Applications Development and Diagnostics (ADD) Team Summary Part 2

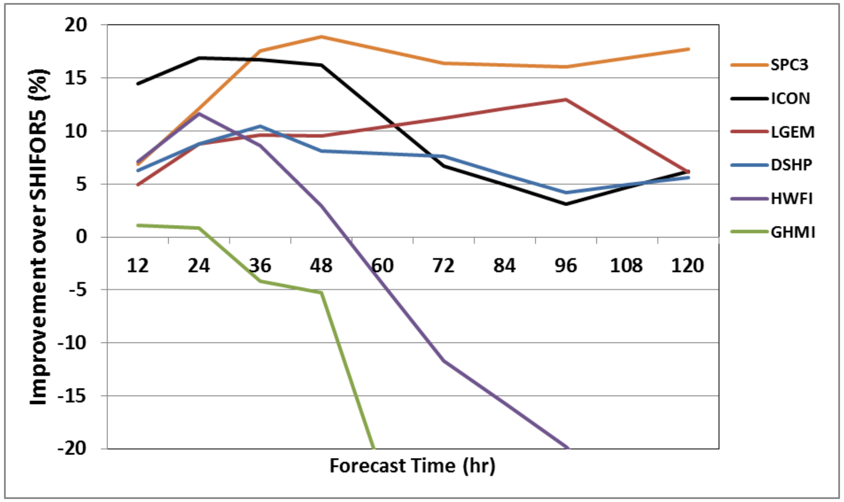
Mark DeMaria, NOAA/NESDIS

HFIP Annual Review Meeting
Nov. 8-9, 2011, Miami, FL

Input from: Chris Davis, James Doyle, Thomas Galarneau, Lewis Grasso, Eric Hendricks, Rich Hodur, Wallace Hogsett, Hao Jin, Yi Jin, John Knaff, Paul Kucera, Sylvie Lorsolo, Tim Marchok, Kate Maclay, Frank Marks, Brian McNoldy, Jon Moskaitis, Kate Musgrave, Dave Nolan, Paul Reasor, Rob Rogers, Andrea Schumacher, Ryan Torn, Christopher Williams, Jun Zhang

6.1.5 Development of statistical intensity models with multiple regional and global model input

- Statistical Prediction of Intensity from a Consensus Ensemble (SPICE) model
- Combines D-SHIPS and LGEM run off GFS, HWRF and GFDL
- Chosen for stream 1.5 test in 2011
- Real time runs began Aug. 1st

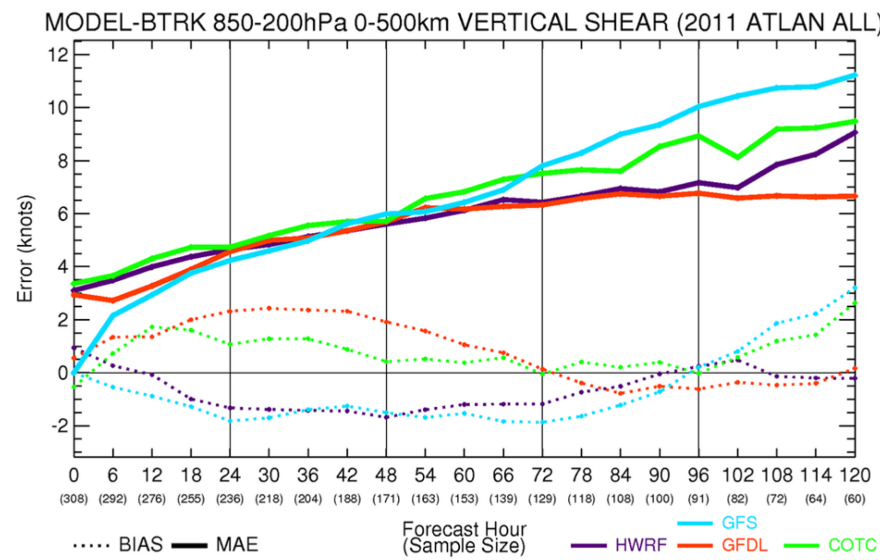


Homogeneous verification for operational intensity models and SPICE for all available 2011 Atlantic cases (Franklin-Rina). N=257 at 12 h, N=111 at 120 h

From Kate Musgrave, Brian McNoldy

6.1.10 Provide initialization and large-scale diagnostic code to EMC for 2011 season pre-implementation testing

- SHIPS diagnostic code provided to EMC
  - Run in real time during 2011
- Adapted to COAMPS-TC by Y. Jin
- Also provided to W. Lewis, UW, R. Torn SUNY and TCMT
- Plans for diagnostic verification code to EMC for pre-2012 tests



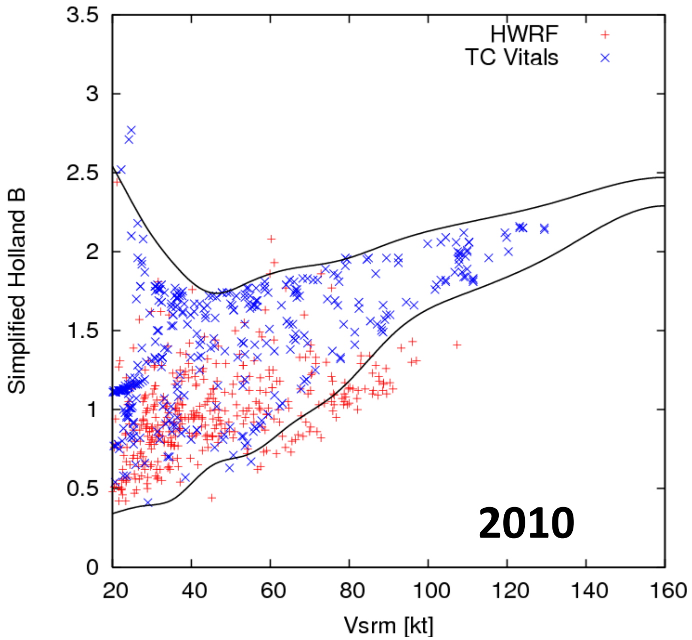
Vertical shear errors and biases for 2011 Atlantic season for GFS, GFDL, HWRF and COAMPS-TC.
GFS analyses used for "ground truth"

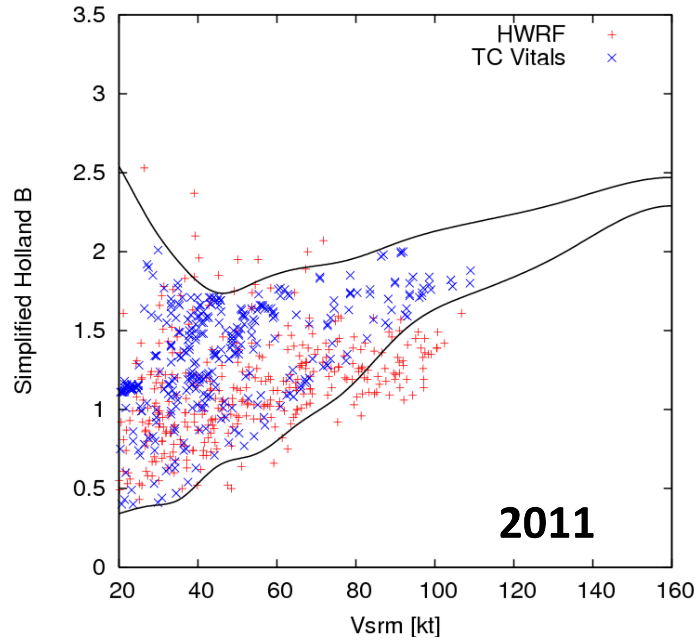
From Brian McNoldy

6.1.11 Extend ESRL global ensemble model cyclone classification system, including TC genesis, and develop prototype ensemble products

- Upgrades were made to ESRL global model web page
- 3 Prototype Ensemble Products Being Developed
  1. Genesis ensembles from global models
     - T. Marchok (lead), S. Majumdar, A. Schumacher, M. Fiorino, J. Whitaker, J. Peng
  2. Combined track/intensity/structure ensembles from regional models
     - J. Moskaitas (lead), W. Lewis, Z. Zhang, J. Peng, A. Aksoy, F. Zhang, R. Torn
  3. Hybrid dynamical-statistical wind probabilities
     - M. DeMaria (lead), A. Schumacher, K. Musgrave, P. McCaslin
- Coordinated on bi-weekly ensemble calls lead by B. Etherton

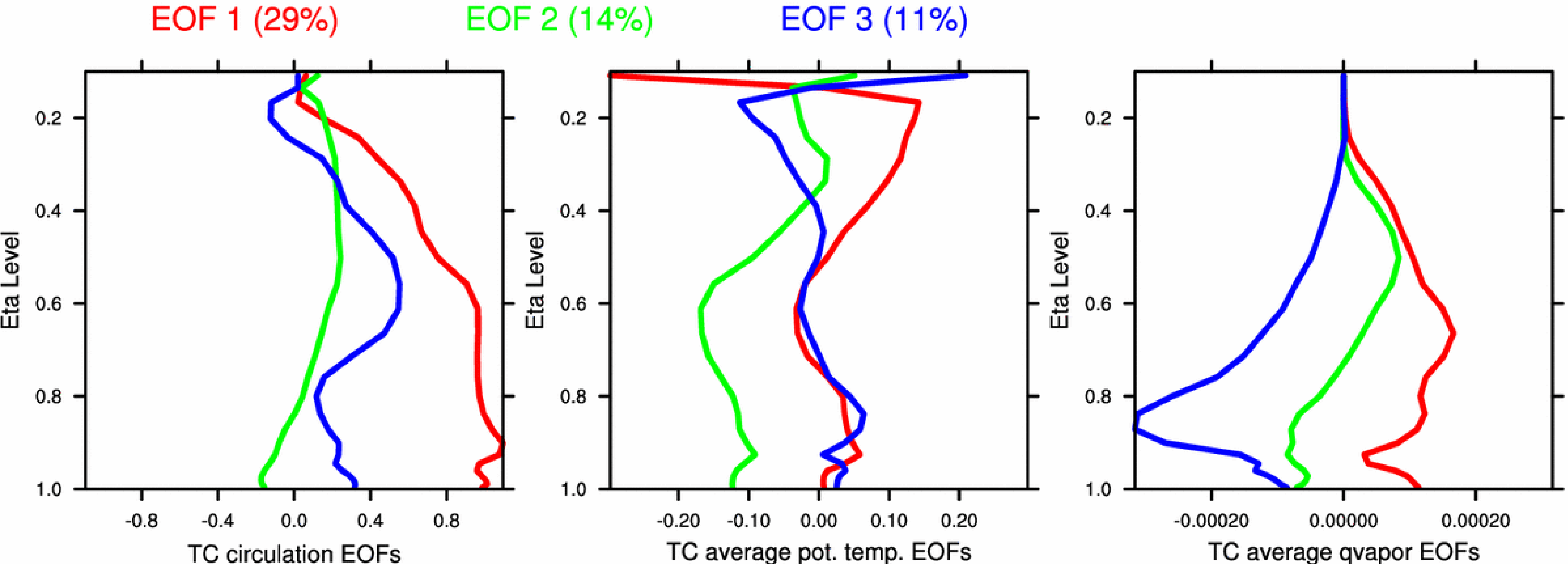
6.1.12 Develop new diagnostic techniques for intensity and structure, including Holland B and balance model parameters, Lagrangian metrics for HWRF and AHW, COAMPS-TC adjoint-based diagnostics, and ensemble-based sensitivity studies for AHW



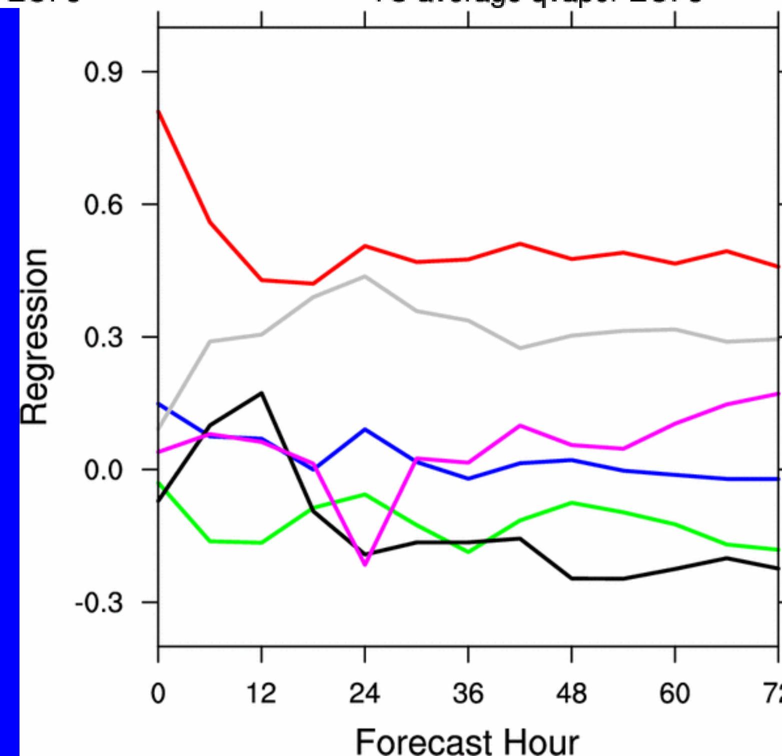


Holland B ~ $V^2/\Delta P$

From John Knaff



Sensitivity of 850 hPa circulation at various lead times to First, Second, and Third EOF of initial circulation, temperature and moisture within the vortex, time-average SST, **Shear magnitude**, and upshear moisture for pre-Karl (2010). This calculation is done with a 96 member AHW ensemble.



From Ryan Torn

COAMPS-TC

Model Diagnostic Activities 2011 Summary

Yi Jin, James Doyle, Jon Moskaitis, Hao Jin,
Eric Hendricks, and Rich Hodur

- **Collaboration with the ADD team on the diagnostic code and Hurricane Maria (2011) analysis**
- **Synoptic diagnostics for the two month period (Aug-Sept. 2010) to evaluate impacts of various physics parameterization (e.g. radiation, cumulus, and PBL) for TC track and intensity**
- **TC inner-core diagnostics for new parameterizations (e.g. microphysics) for challenging storms**
- **Adjoint diagnostic analysis for model sensitivity to initial conditions and synoptic environment at various resolutions**
- **Continuing collaboration with Grasso of CIRA for applications of GOES synthetic imagery in diagnosing behavior of microphysics schemes**
- **Development and testing of TCDI vortex initialization, which could be shared easily with HFIP partners**
    - ***Addresses 6.1.14 to develop vortex initialization methods***

6.1.13 Vortex and convective scale analysis of HWRFx and HWRF, including comparison with Doppler radar and GPS dropsondes, and histogram analysis of HWRF and AHW

Databases used in composites

Doppler database

40 radar analyses in 8 different storms

Storm name	Year	Best track intensity (kt)	Number of radar analyses
Guillermo	1997	105	4
Fabian	2003	110	3
Isabel	2003	140	7
Frances	2004	110-125	8
Ivan	2004	105	4
Katrina	2005	110-150	4
Rita	2005	125-145	6
Paloma	2008	125	4

GPS dropsonde database

794 dropsondes in 13 different storms

Storm name	Year	Best track intensity (kt)	Number of sondes
Erika	1997	83-110	40
Bonnie	1998	68-93	76
Georges	1998	66-78	39
Mitch	1999	145-155	28
Bret	1999	75-90	33
Dennis	1999	65-70	7
Floyd	1999	80-110	40
Fabian	2003	68-120	131
Isabel	2003	85-140	162
Frances	2004	68-83	62
Ivan	2004	65-135	123
Dennis	2005	65-70	7
Katrina	2005	68-100	46

HWRFx database

34 model output times in 16 runs of 5 different storms
3 km smallest grid length for all runs

Storm name	Year	Simulated intensity (kt)	Number of output times
Wilma	2005	68-135	7
Rita	2005	98-145	8
Katrina	2005	68-130	8
Karl	2010	100-105	3
Earl	2010	105-120	8

Eyewall vertical velocity

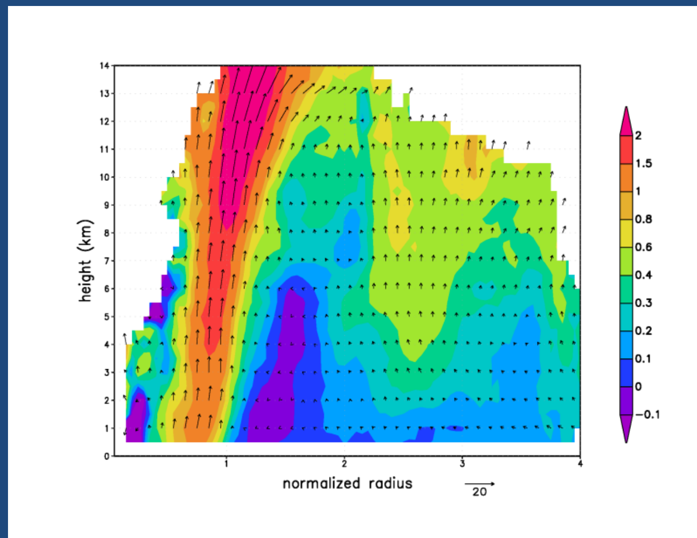
Examine multiple aspects of eyewall vertical velocity:

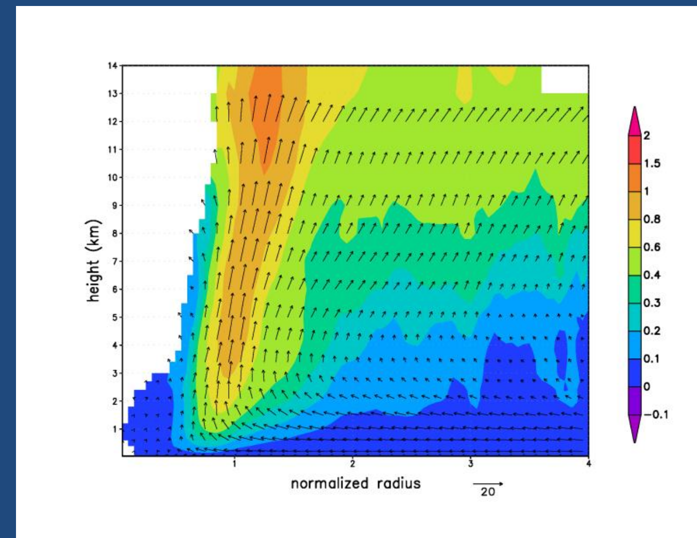
1) axisymmetric structure 2) asymmetric structure 3) full distribution

Doppler

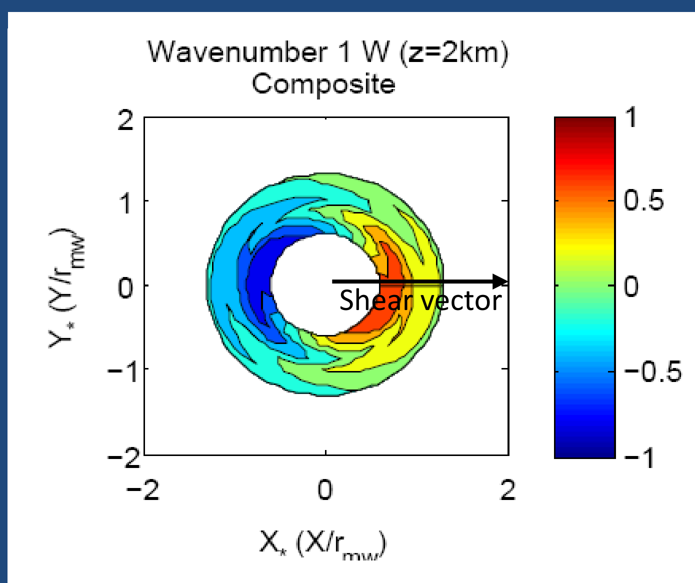
HWRFx

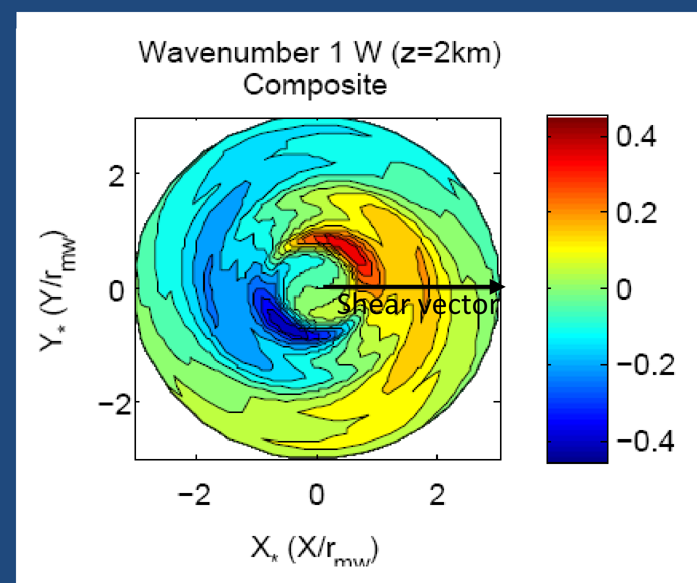
Axisymmetric





Asymmetric

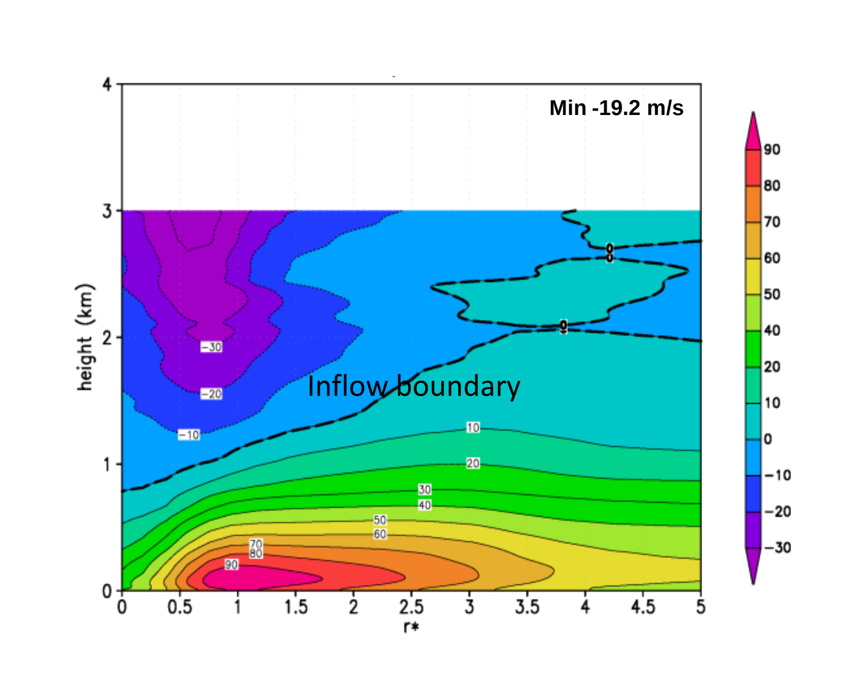




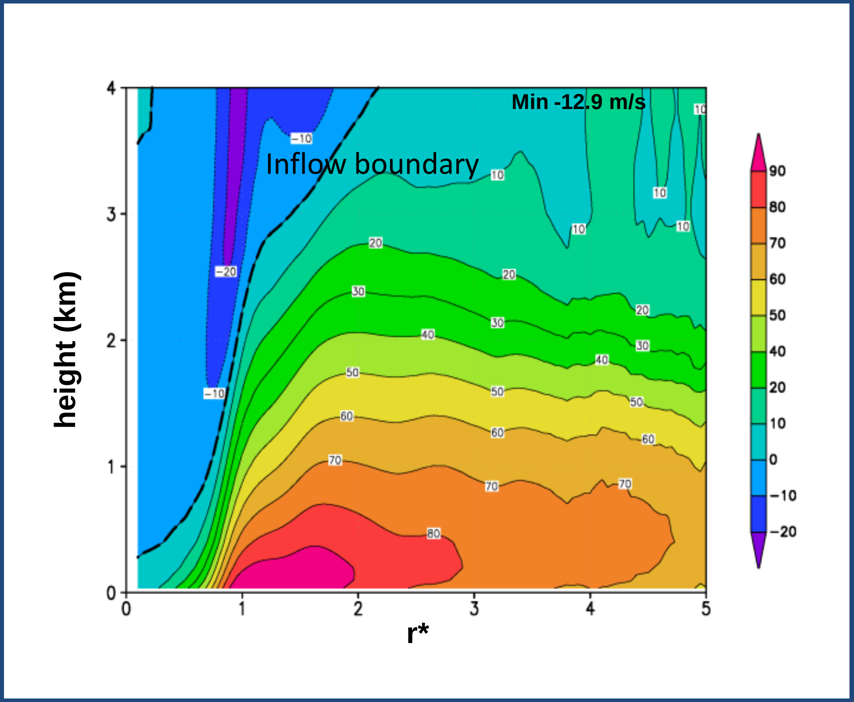
Radial flow in boundary layer

Examine axisymmetric radial flow, normalized by peak inflow value

Dropsonde



HWRFx



For boundary layer radial flow, this configuration of HWRFx produces:

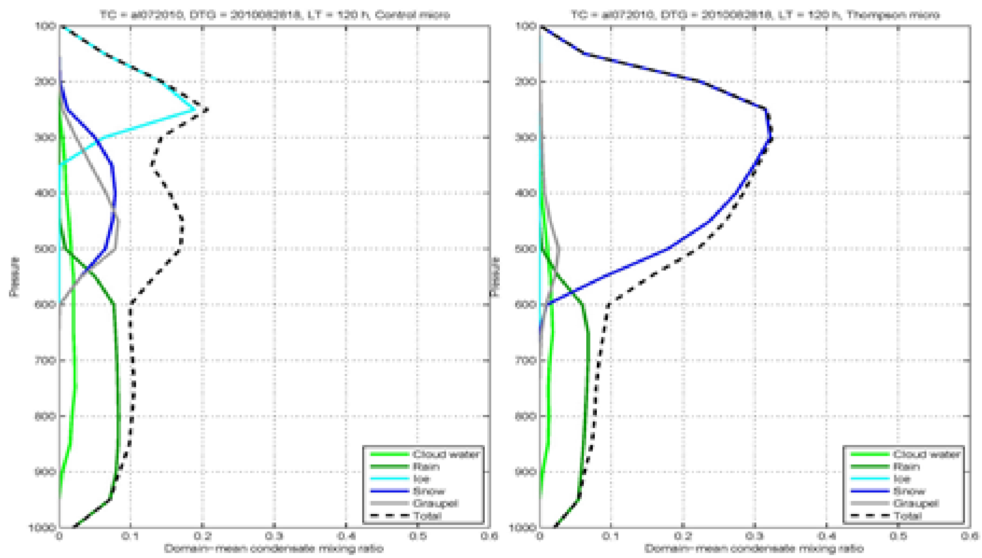
- weaker peak inflow values
- much deeper inflow layer

6.1.15 Develop track forecast diagnostics and perform physical parameterization impact studies for COAMPS-TC

COAMPS-TC

Inner Core Diagnostic (Domain averaged)

Vertical distribution of hydrometeors 84 h forecasts



- The Thompson V3 microphysics scheme has been implemented in COAMPS-TC and tested for TC cases. The domain-averaged diagnostics in the 5-km domain provides insight into the behavior of the different microphysics schemes.
- The Thompson scheme produces much more snow at upper levels and much less ice and graupel than the current scheme. The microphysics impacts TC intensity and structure seen in radar reflectivity and synthetic imagery.

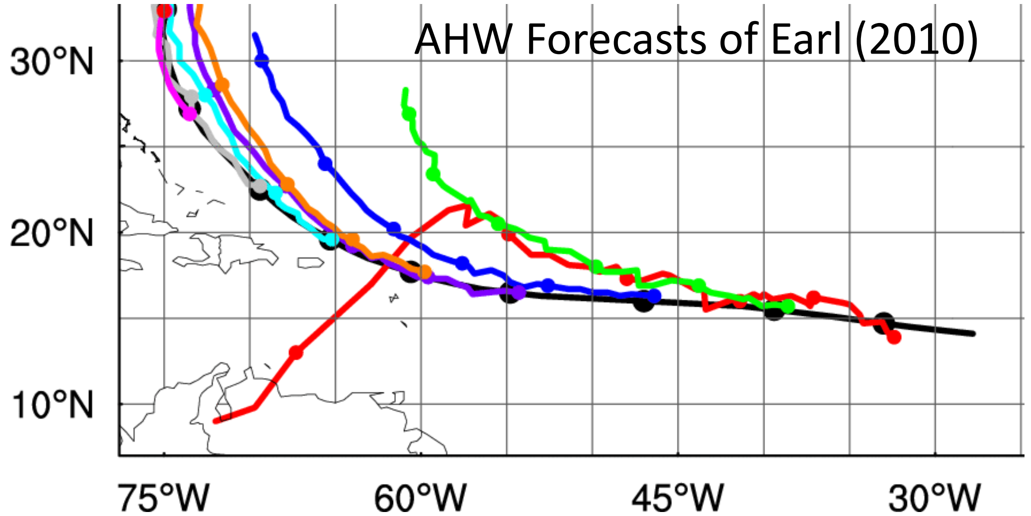
From Yi Jin

Computing and Understanding Forecast Errors in TC Motion

Thomas Galarneau and Christopher Davis
National Center for Atmospheric Research

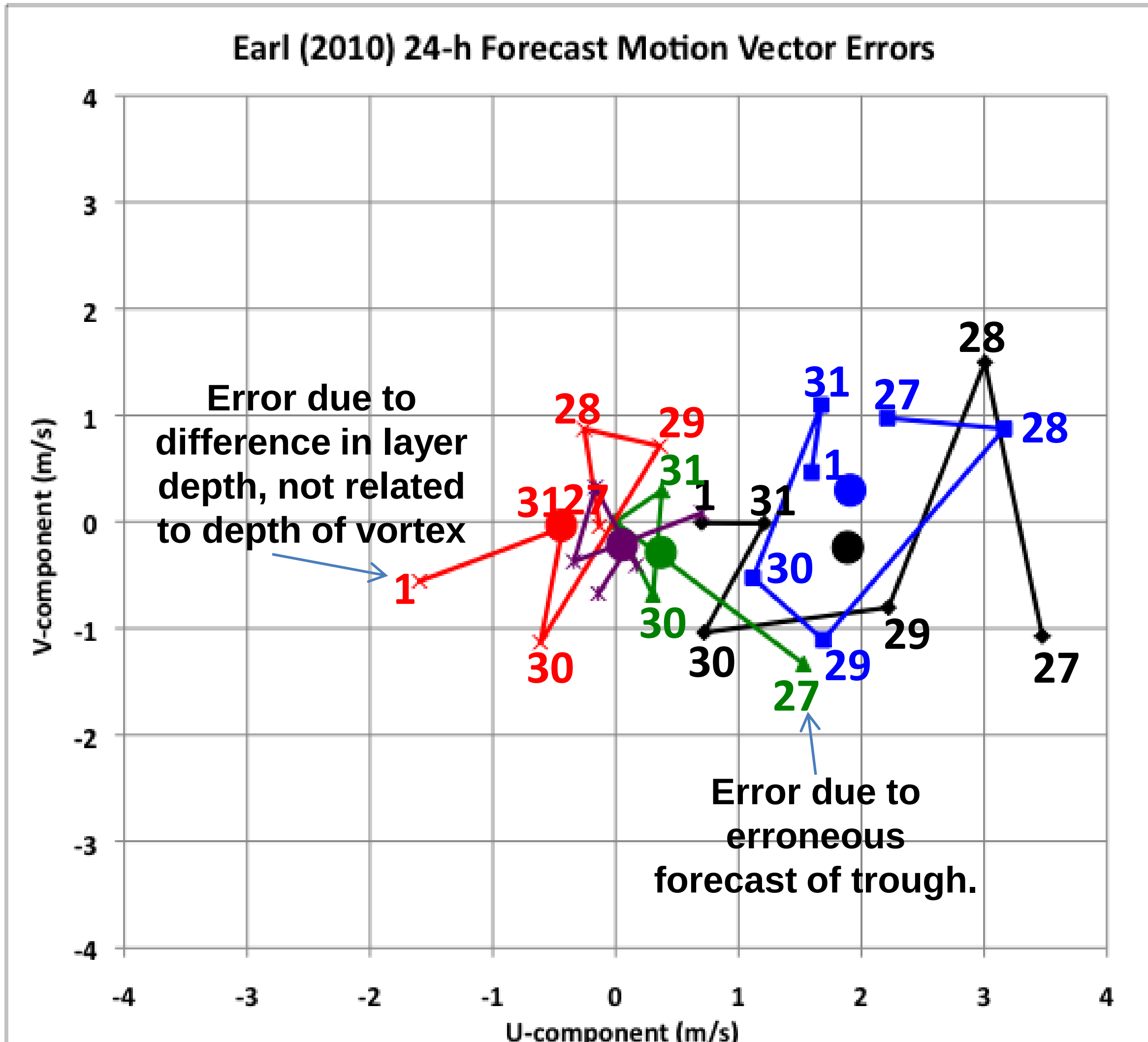
Questions:

1. How well does the traditional definition of steering motion work?
2. How does the steering flow relate to vortex structure?
3. What is the contribution to track error of environmental wind error versus TC structure error?
4. How can we relate these errors to specific model process errors?



Contribution to Storm Motion Error

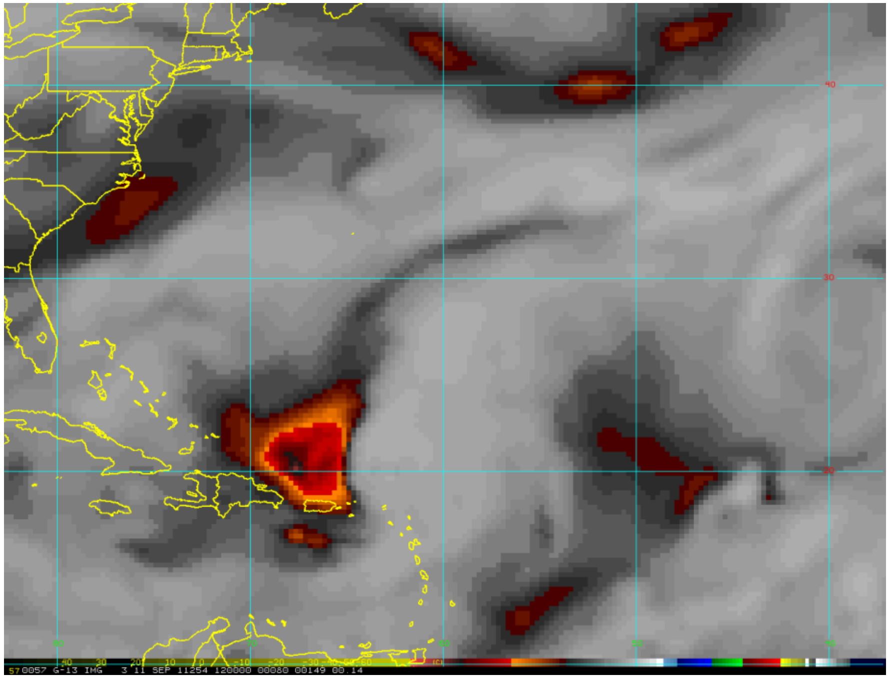
Verifying 0000 UTC
27 Aug–1 Sep 2010



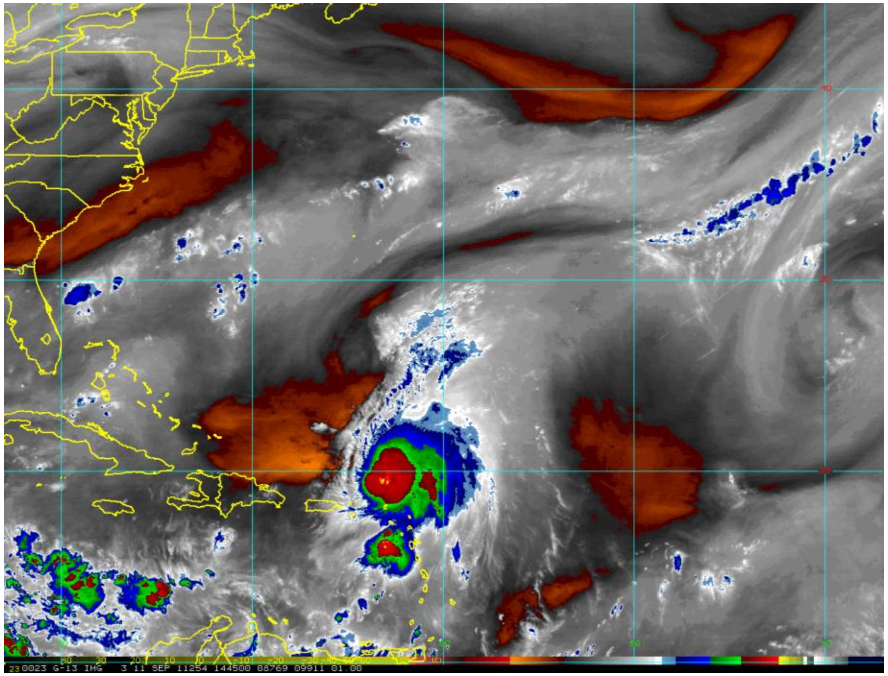
Actual error
Environment wind error
Removal radius error
Vertical depth error
Residual

- **Main forecast error is environmental flow (storm moves too slowly westward)**
- **Residual is small**
- **Other terms can be large at times: errors in nearby features, strong shear**

6.2.1 and 6.2.2 Forward Models for Microwave and IR Imagery



Synthetic GOES-East Ch 3 from Maria HWRF real time run 9/11/11 12 UTC



Observed GOES-East Ch 3

From Lewis Grasso and Janna O'Connor

Hurricane Maria Case Study

- Requested by EMC to better understand HWRF response to vertical shear
- Participation by HRD, CIRA, TCMT, NRL
- Large environment errors or erroneous storm response to shear?
- Inter-model (HWRF, GFDL, COAMPS-TC) comparison
- Composite studies of other shear cases
- Comparison with in situ and satellite observations when possible

Part 2 Summary

- Statistical ensemble intensity model performed well in 2011, more global model input to be added in 2012
- Ensemble product development underway
- Many diagnostic efforts for synoptic, vortex and cloud scale
  - Basic large SHIPS diagnostics code allowing for model inter-comparisons
  - New track diagnosis for AHW
  - Sophisticated adjoint diagnostics for COAMPS-TC
- Comparisons with aircraft in situ and radar data revealing model limitations
- Hurricane Maria study example of “rapid response team”

Reference Slides

NCAR Input

Computing and Understanding Forecast Errors in TC Motion

Thomas Galarneau and Christopher Davis
National Center for Atmospheric Research

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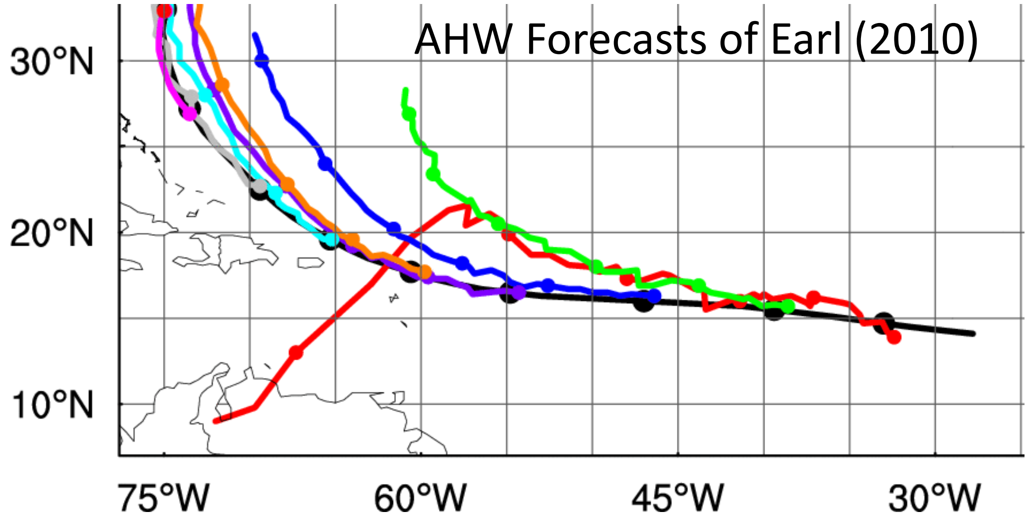
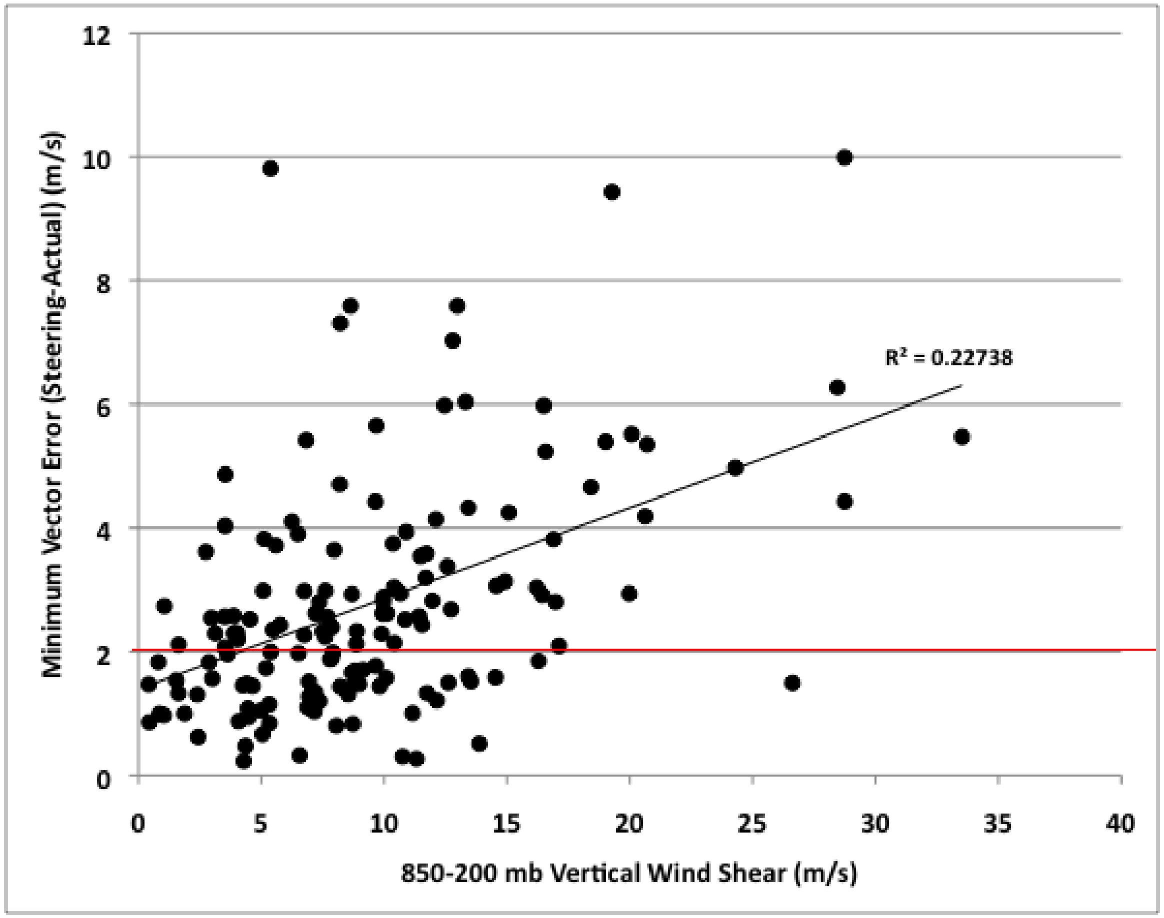


“Standard” Deep Layer Steering Flow



850-200 mb Steering Flow defined as average within 500 km after TC removal

(vorticity and divergence inversion technique)

- 24 h forecasts from AHW
- TC motion computed from +/- 6 h positions
- Error here is difference of the deep-layer wind and TC motion vectors (not forecast error)

- **DLM wind has errors less than 2 m/s only 41% of the time!**
- **Worse in shear**
- **Similar result for observed storm/CFSR analyses**

Defining the Steering Flow

- Steering-layer depth and radius of TC removal are allowed to vary.
- Can be different in model (AHW) and obs (CFSR)
- Allows good match 95% of the time
- Differences in layer depth and/or radius of removal are related to errors in TC structure and/or environmental features

TC Earl at 0000 UTC 28 August 2010

Observed (V_o defined from HURDAT; V_{env} defined from CFSR):

PARM	RADIUS	FCST (hr)	YYMMDD/HH	850-800	850-750	850-700	850-650	850-600	850-550	850-500	850-450	850-400	850-350	850-300	850-250	850-200
MAG	1 DEG	0	100828/00	3.23021	2.96697	2.74152	2.63183	2.48281	2.28586	1.96351	1.615	1.42345	1.24095	1.39442	1.76718	2.01949
MAG	2 DEG	0	100828/00	2.02417	1.66862	1.31084	0.980819	0.789696	0.748532	0.72949	0.638633	0.481609	0.446551	0.604524	0.753187	0.866542
MAG	3 DEG	0	100828/00	1.69308	1.56641	1.14153	0.490275	$\boxed{\textbf{0.073603}}$	0.195315	0.32431	0.428402	0.441654	0.331182	0.378454	0.445014	0.454048
MAG	4 DEG	0	100828/00	2.27777	2.17382	1.91171	1.40858	0.985558	0.653867	0.443417	0.32192	0.291576	0.484405	0.606313	0.651183	0.592695
MAG	5 DEG	0	100828/00	3.22835	2.94173	2.52014	2.09943	1.72102	1.39993	1.26611	1.21432	1.19725	1.29915	1.35012	1.27619	1.18048
MAG	6 DEG	0	100828/00	3.66178	3.41196	2.92657	2.52249	2.15694	1.9313	1.88043	1.89677	1.88768	1.92548	1.90881	1.78308	1.67383
MAG	7 DEG	0	100828/00	4.48702	4.27581	3.86693	3.40343	3.07718	2.89782	2.80045	2.80226	2.76716	2.78523	2.7696	2.66921	2.58028
MAG	8 DEG	0	100828/00	5.28754	5.20924	4.91152	4.43546	4.10759	3.93088	3.81243	3.79122	3.73623	3.73839	3.75924	3.70002	3.59566

Best match = 300-km removal radius; 850–600 mb layer

Tables show magnitudes of mismatch between averaged flow and storm motion for different choices of removal radius and layer depth

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AHW (V_m defined from ATCF; V_{env} defined from AHW grids)

TYPE	RADIUS	FCST (hr)	YYMMDD/HH	850-800 DIR	850-750 DIR	850-700 DIR	850-650 DIR	850-600 DIR	850-550 DIR	850-500 DIR	850-450 DIR	850-400 DIR	850-350 DIR	850-300 DIR	850-250 DIR	850-200 DIR
MAG	1 DEG	24	100828/00	1.6839	1.63842	1.44294	1.04944	0.553804	0.420056	0.859949	1.26558	1.56217	1.79345	1.91233	2.13733	2.51061
MAG	2 DEG	24	100828/00	1.60632	1.63517	1.57068	1.29558	0.873605	0.438606	0.192508	0.372233	0.551515	0.630739	0.616339	0.723165	1.0152
MAG	3 DEG	24	100828/00	1.2458	1.28286	1.2278	1.01466	0.713402	0.416303	0.181593	$\boxed{\textbf{0.033087}}$	0.156847	0.23077	0.262621	0.455872	0.680331
MAG	4 DEG	24	100828/00	1.95523	1.85696	1.62401	1.35124	1.09943	0.878286	0.689193	0.546409	0.480832	0.524995	0.676366	0.856093	1.0316
MAG	5 DEG	24	100828/00	2.37226	2.29739	2.12923	1.93438	1.71872	1.49988	1.30668	1.15585	1.06281	1.08875	1.23092	1.36944	1.53055
MAG	6 DEG	24	100828/00	2.54576	2.57328	2.51681	2.39892	2.22556	2.0213	1.8261	1.67275	1.59151	1.59869	1.69876	1.81421	1.94499
MAG	7 DEG	24	100828/00	2.80237	2.90543	2.9072	2.81167	2.64153	2.44837	2.2729	2.14009	2.0777	2.08169	2.13031	2.20367	2.30714
MAG	8 DEG	24	100828/00	3.02413	3.15902	3.19386	3.09716	2.91943	2.73016	2.57151	2.46155	2.41094	2.41195	2.44432	2.50519	2.59504

Best match = 300-km removal radius; 850–450 mb layer

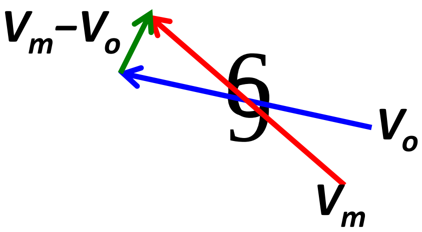
Diagnosing Storm Motion Error

Obs steering flow

$$\vec{V}_o = \frac{1}{p_{to} - p_b} \int_{p_b}^{p_{to}} \{\vec{v}_o\}\, dp \qquad \{\vec{v}_o\} = \frac{1}{\pi R_o^{\,2}} \int_0^{2\pi} \int_0^{R_o} \vec{v}_o r\,dr$$

Model steering flow

$$\vec{V}_m = \frac{1}{p_{tm} - p_b} \int_{p_b}^{p_{tm}} \{\vec{v}_m\}\, dp \qquad \{\vec{v}_m\} = \frac{1}{\pi R_m^{\,2}} \int_0^{2\pi} \int_0^{R_m} \vec{v}_m r\,dr$$



$$\{\hat{\vec{v}}_m\} = \frac{1}{\pi R_o^{\,2}} \int_0^{2\pi} \int_0^{R_o} \vec{v}_m r\,dr$$

R=radius of TC removal, p_t=top of layer, p_b=bottom of layer; subscript 'o' is for observed, 'm' for model

$$\underbrace{\vec{V}_m - \vec{V}_o}_{\textbf{actual error}} = \underbrace{\left[\frac{1}{p_b - p_{to}} \int_{p_b}^{p_{to}} \left(\{\hat{\vec{v}}_m\} - \{\vec{v}_o\} \right) dp \right]}_{\textbf{environment wind error}} +$$

$$\left[\underbrace{\frac{1}{p_b - p_{to}} \int_{p_b}^{p_{to}} -\left(\{\hat{\vec{v}}_m\} - \{\vec{v}_m\} \right) dp}_{\textbf{removal radius error}} + \underbrace{\frac{1}{p_b - p_{tm}} \left\{ \int_{p_b}^{p_{to}} \left[\frac{p_{to} - p_{tm}}{p_b - p_{to}} \right] \{\vec{v}_m\} dp + \int_{p_{to}}^{p_{tm}} \{\vec{v}_m\} dp \right\}}_{\textbf{vertical depth error}} \right]$$

Contribution to Storm Motion Error

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27 Aug–1 Sep 2010

Actual error
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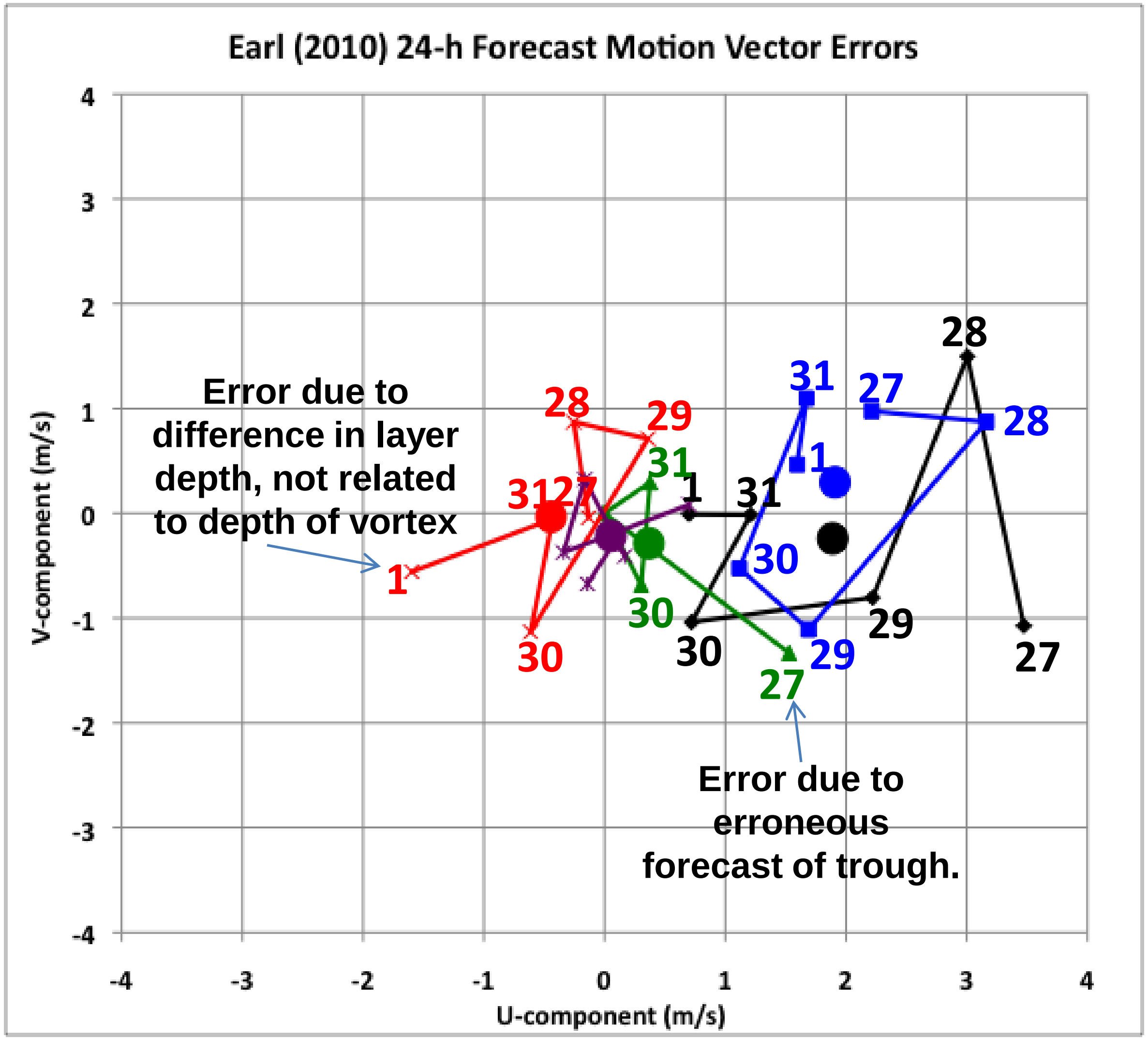
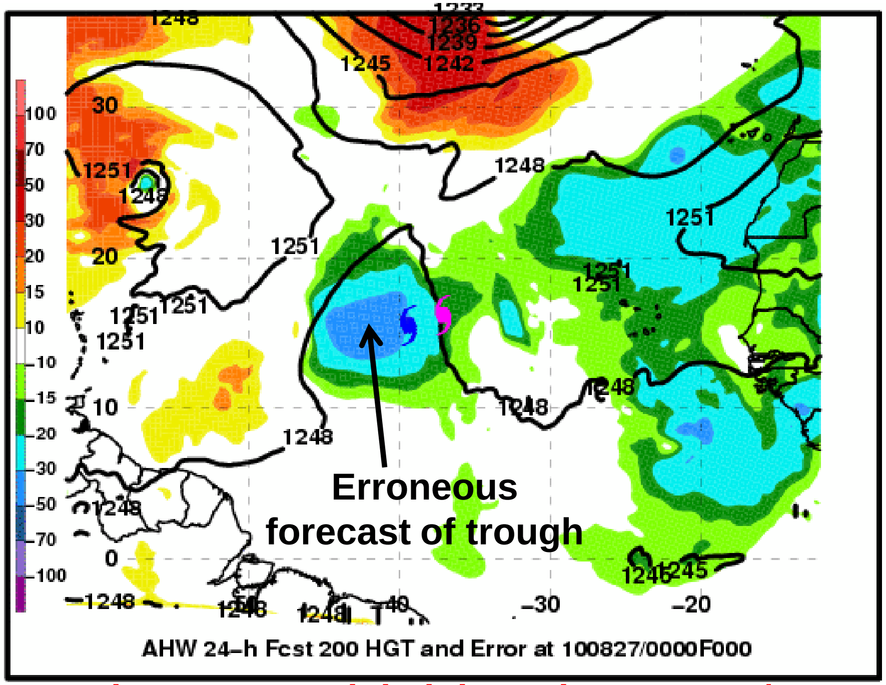
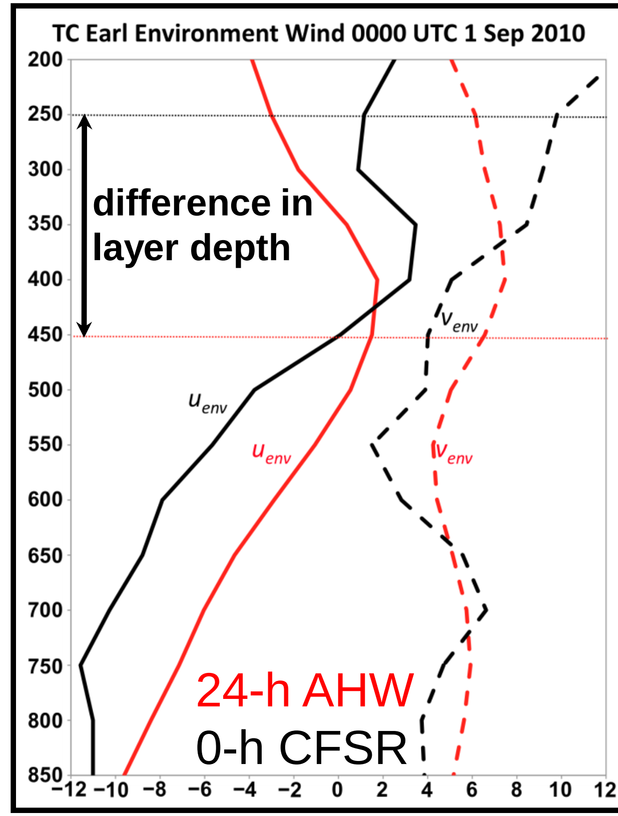
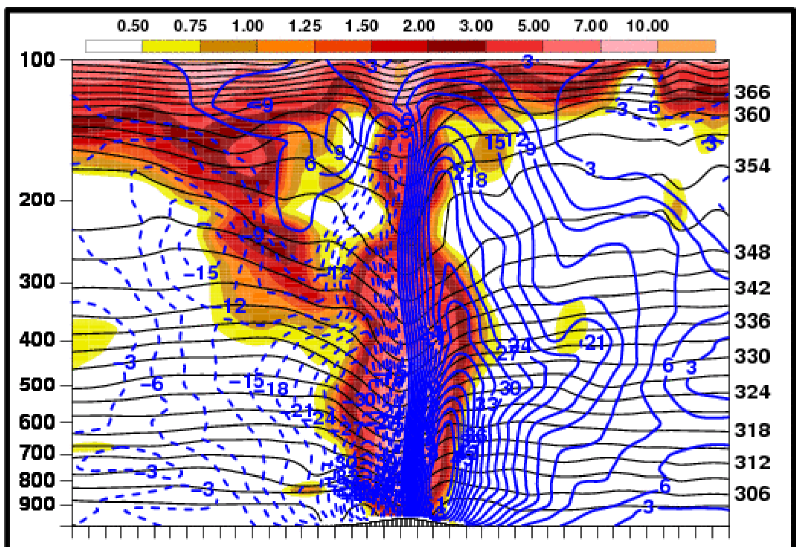


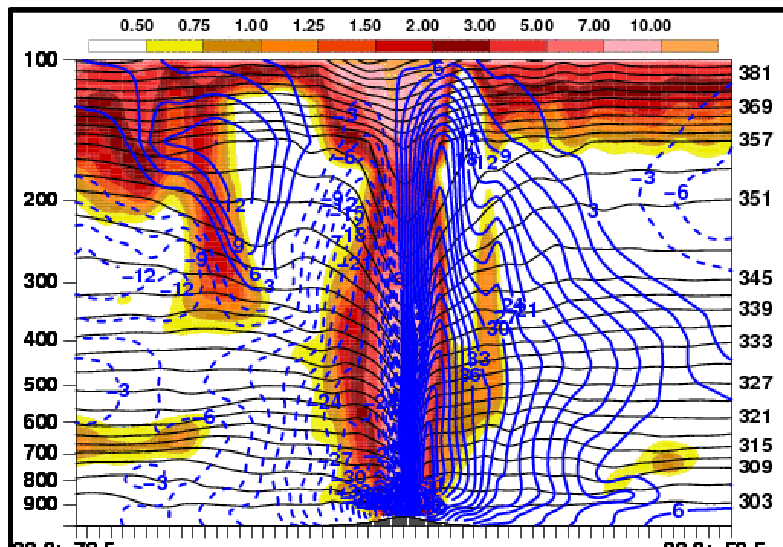


24-h AHW 200 mb height and error v00Z/27





0-h CFSR PV, θ, wind v00Z/1



24-h AHW PV, θ, wind v00Z/1

NRL Input

COAMPS-TC

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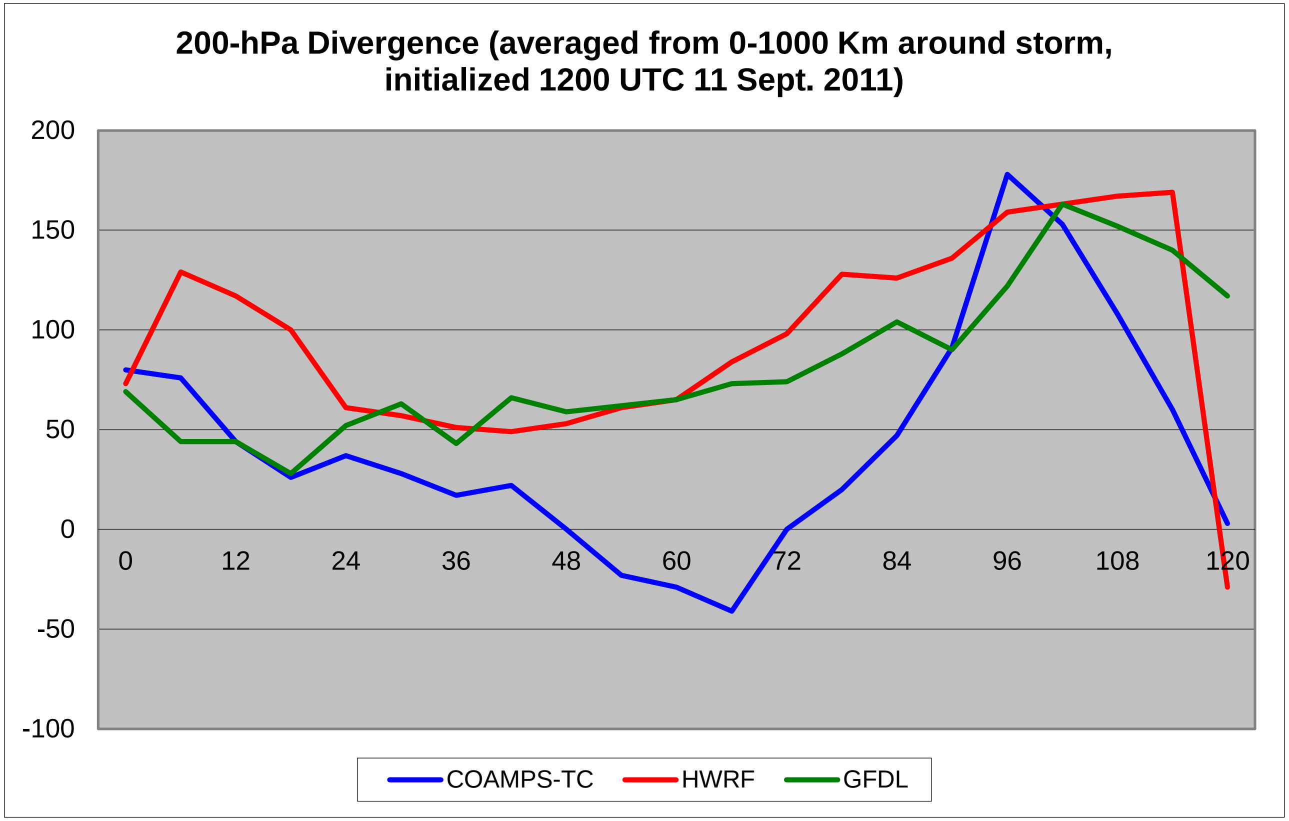
- **Adjoint diagnostic analysis for model sensitivity to initial conditions and synoptic environment at various resolutions**
- **Continuing collaboration with Grasso of CIRA for applications of GOES synthetic imagery in diagnosing behavior of microphysics schemes**
- **Development and testing of TCDI vortex initialization, which could be shared easily with HFIP partners**

COAMPS-TC

Model Diagnostic (I)

Collaborated with the ADD team on the diagnostic code and Maria Analysis

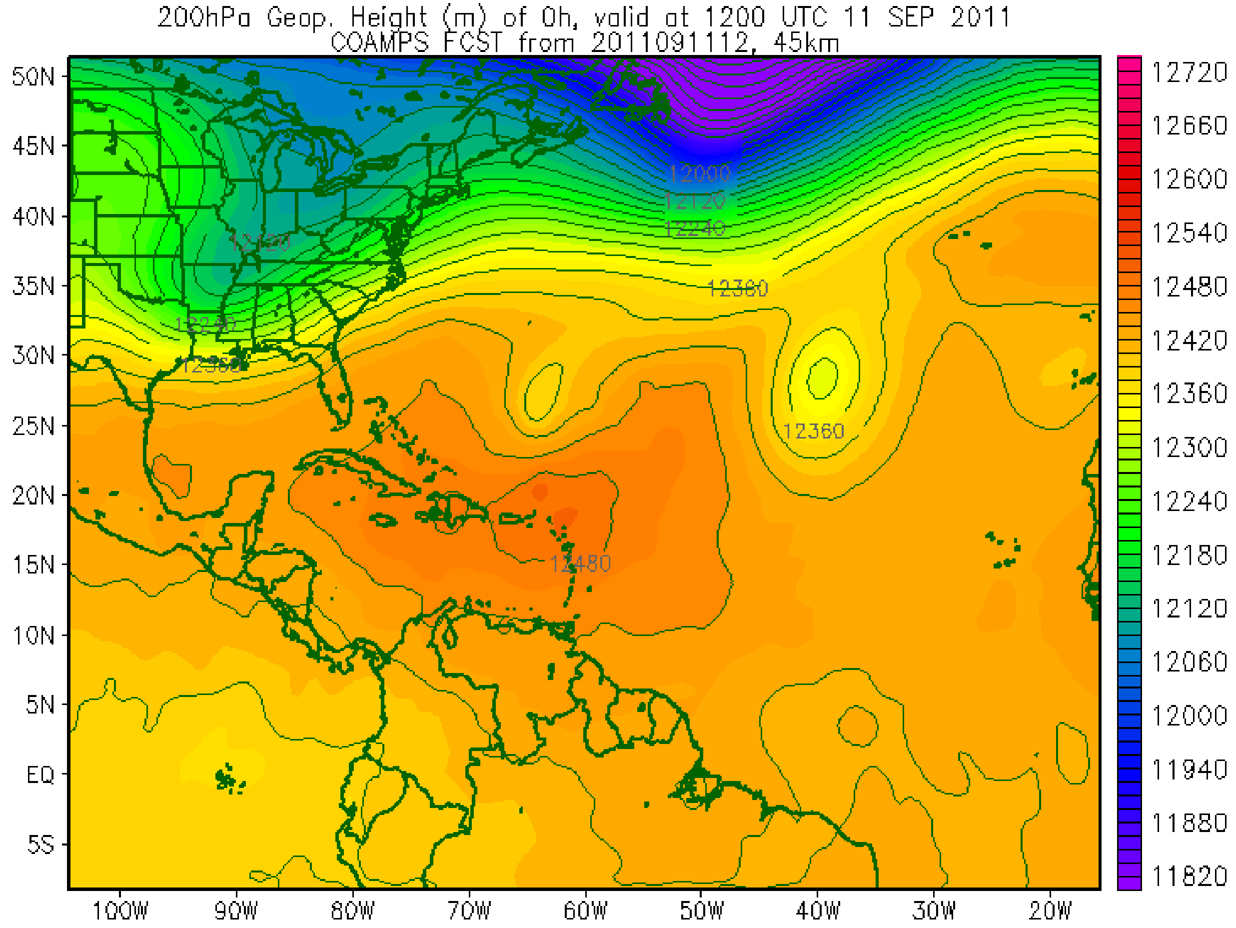


- **COAMPS-TC over-predicted Maria's intensity, but to a lesser extent than HWRF and GFDL.**
- **One difference seen in the diagnostic fields is the much reduced divergence at 200 hPa in COAMPS-TC forecasts than the other two models during the first 72 h.**

COAMPS-TC

Model Diagnostic (II)

200 hPa Geopotential height every 6 h for 120-h real-time forecasts

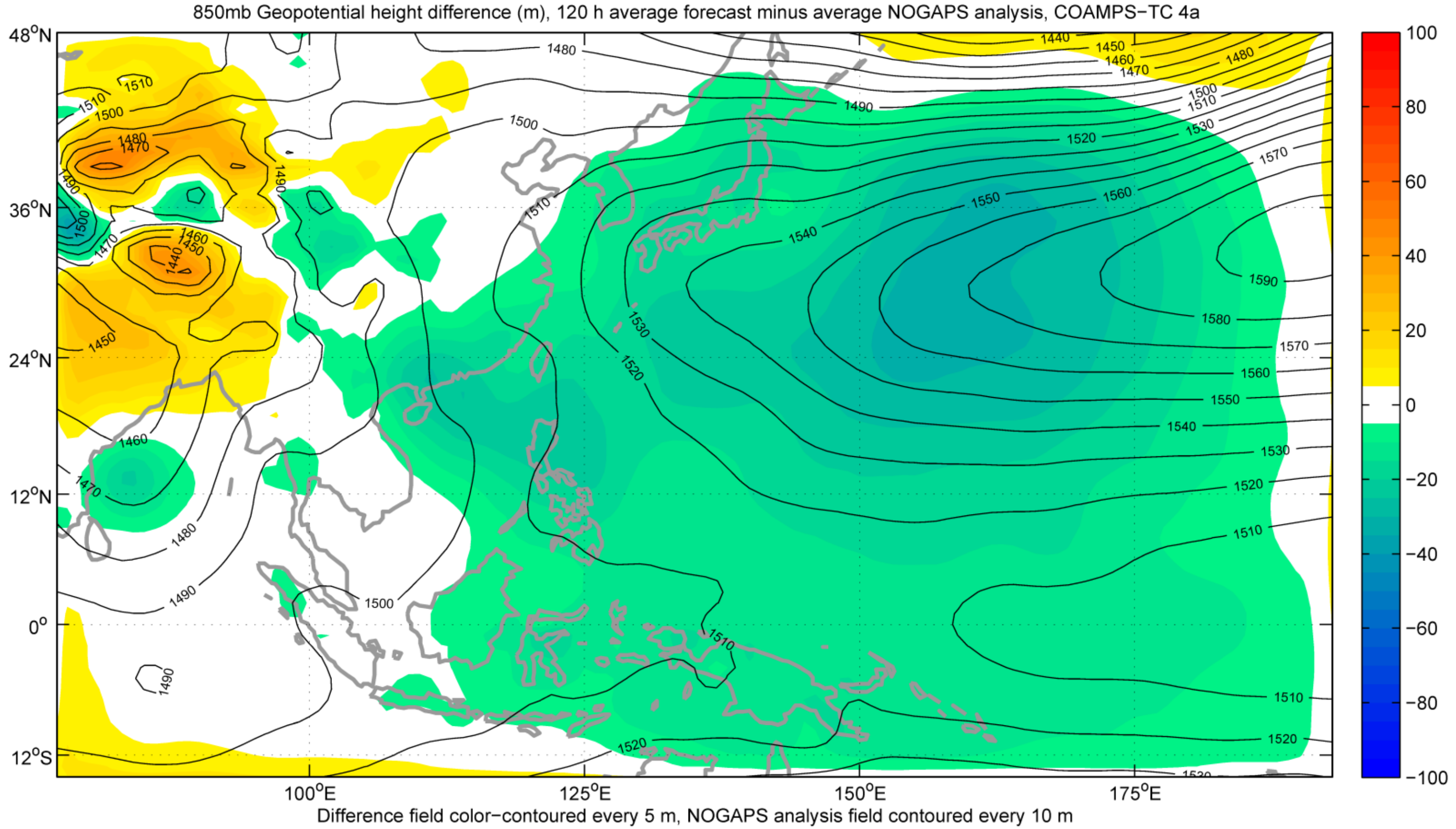


- An upper-level low existed north of Maria for the first 2 days of the simulations. This short-wave disturbance also existed in the satellite track-wind analysis for the same period.

COAMPS-TC

Synoptic Scale Analysis (I)

850-hPa Geopotential Heights difference between COAMPS-TC 120 h forecasts and NOGAPS analysis for Control run (Harshvardhan radiation) Aug-Sept 2010

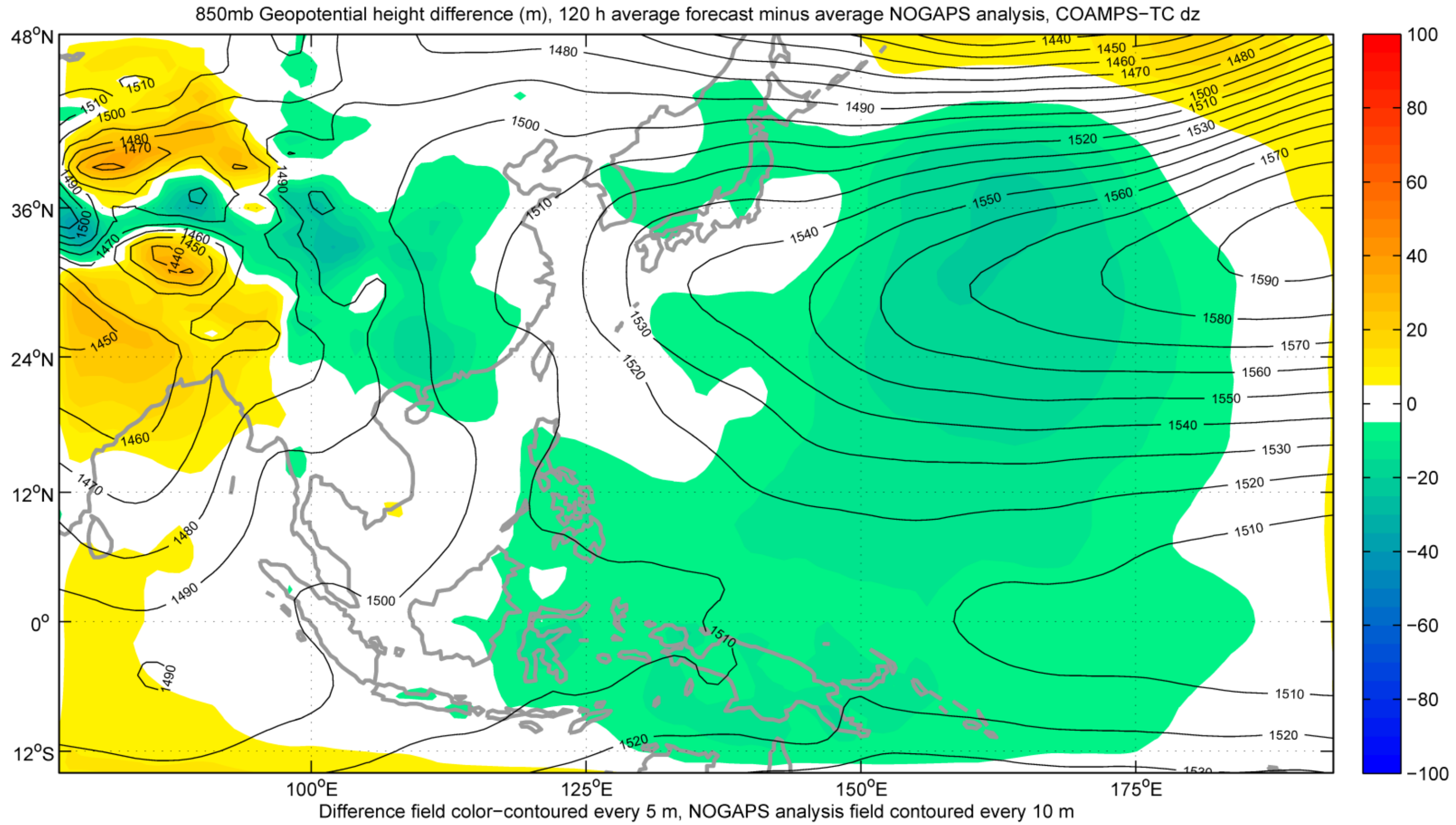


- **A series of synoptic runs over Aug-Sept 2011 were performed to evaluate impacts of various physics parameterizations (radiation, microphysics, cumulus, PBL)**
- **With control radiation, average forecast heights are too low in the subtropical high and South China Sea.**

COAMPS-TC

Synoptic Scale Analysis (II)

850-hPa Geopotential Heights difference between COAMPS-TC 120 h forecasts and NOGAPS analysis for tests using Fu-Liou radiation from Aug-Sept 2010

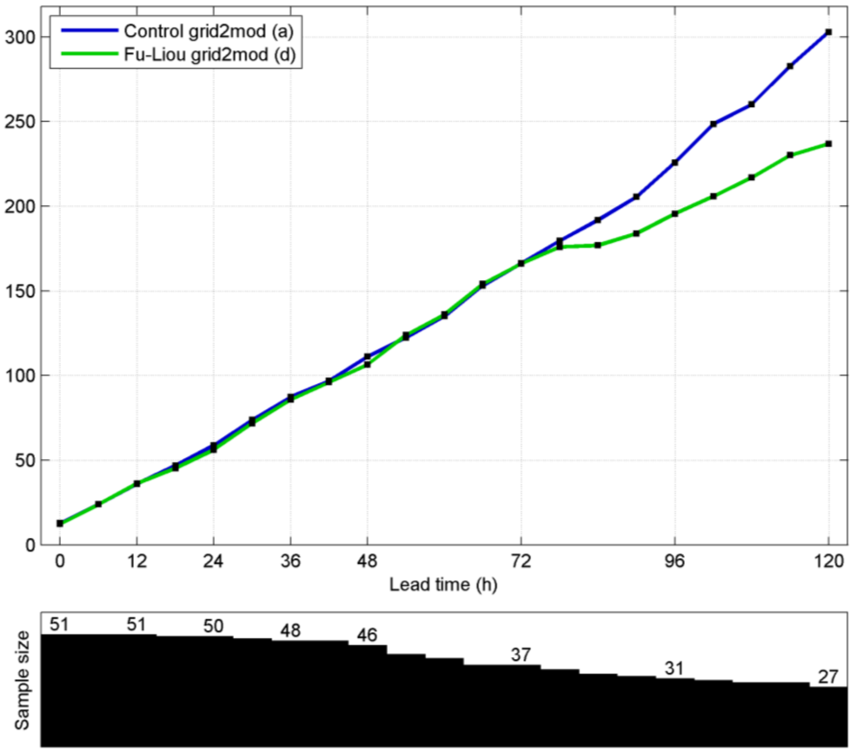


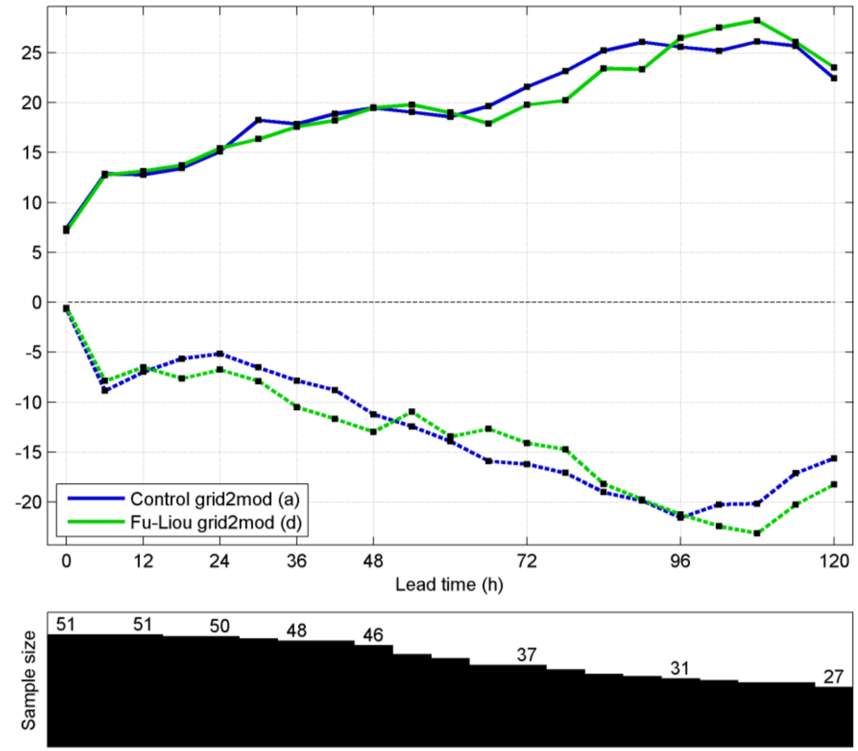
- **Fu-Liou radiation reduces the magnitude of the height bias and improves the average forecast wind field relative to the control radiation.**

COAMPS-TC

Impact on Track and Intensity

5 TC comparison: Control vs. Fu-Liou radiation



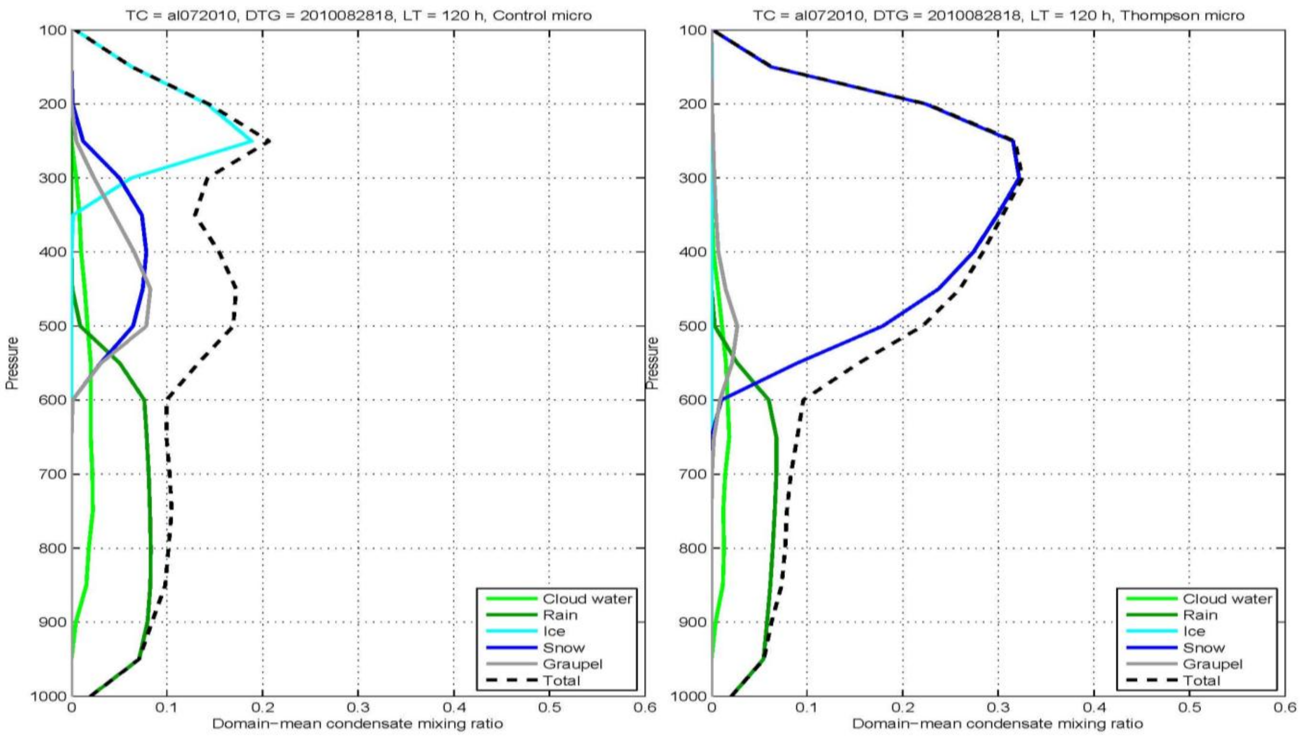


- Fu-Liou radiation reduces the track error for last two days of forecasts.

COAMPS-TC

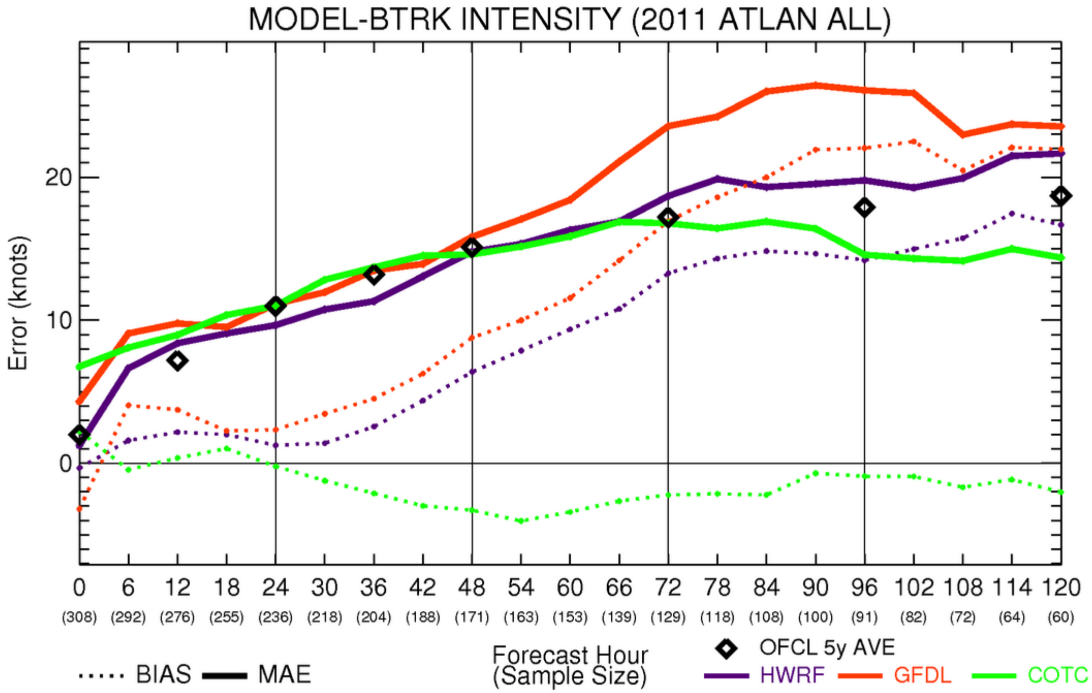
Inner Core Diagnostic (Domain averaged)

Vertical distribution of hydrometeors 84 h forecasts

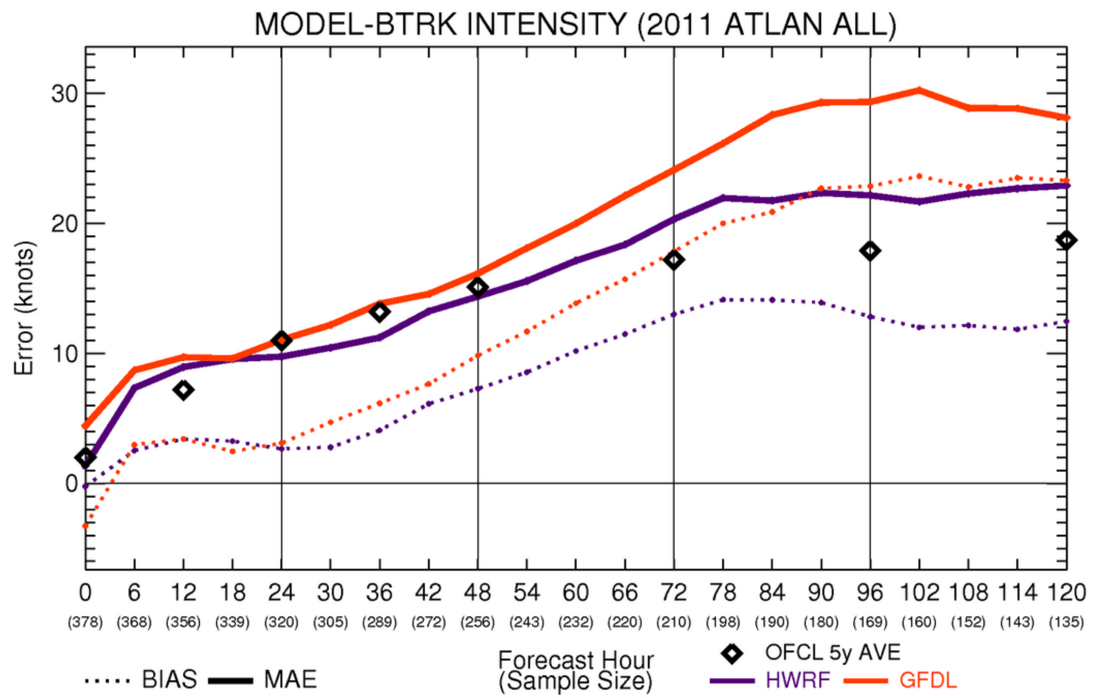


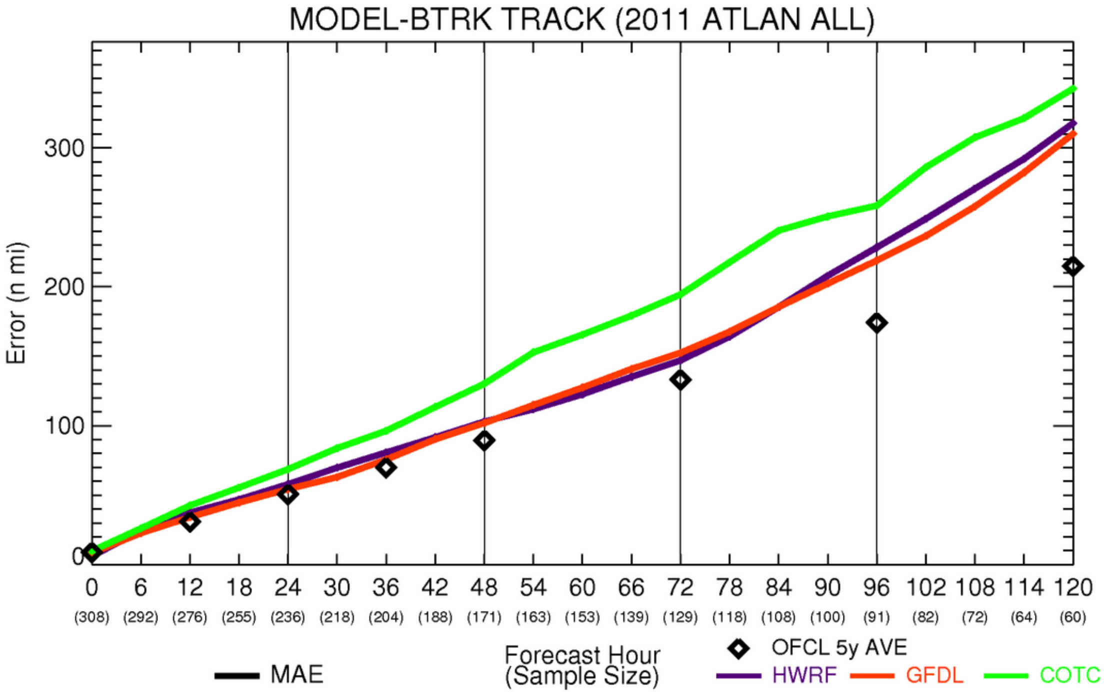
- The Thompson V3 microphysics scheme has been implemented in COAMPS-TC and tested for TC cases. The domain-averaged diagnostics in the 5-km domain provides insight into the behavior of the different microphysics schemes.
- The Thompson scheme produces much more snow at upper levels and much less ice and graupel than the current scheme. The microphysics impacts TC intensity and structure seen in radar reflectivity and synthetic imagery.

NESDIS/CIRA Input

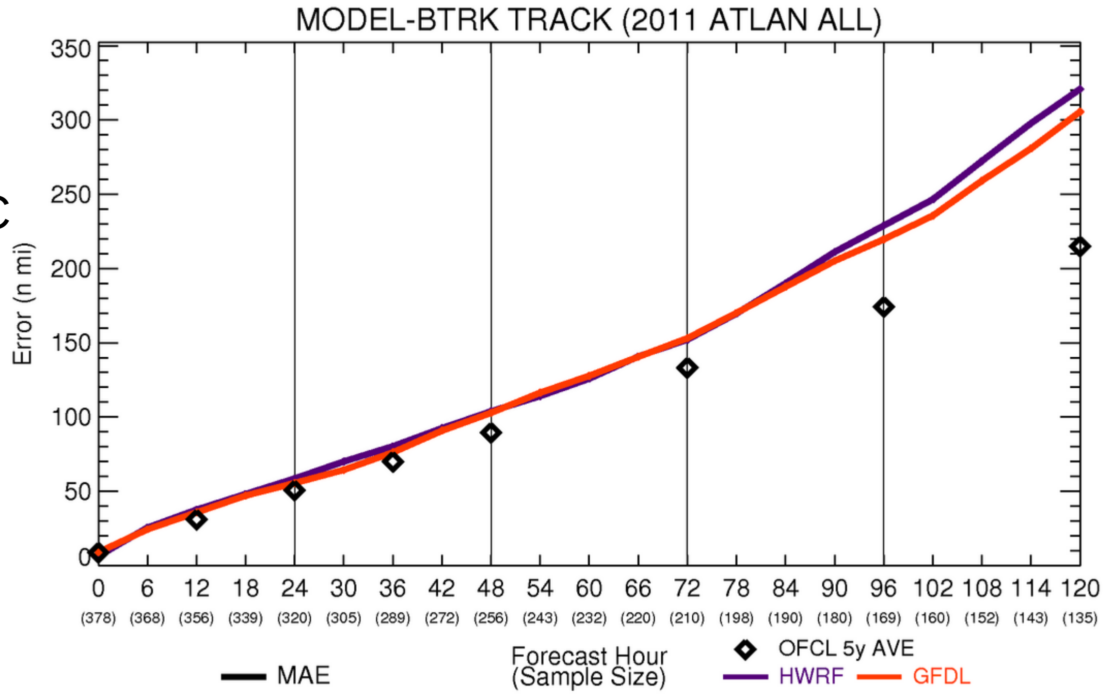


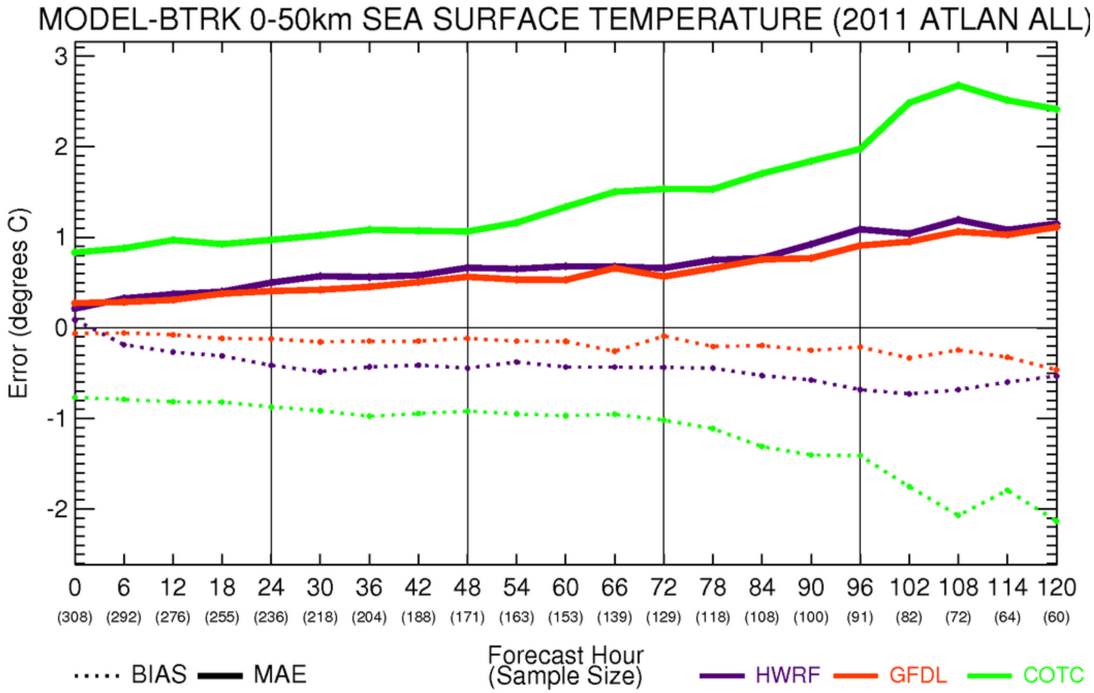
Excluding COTC



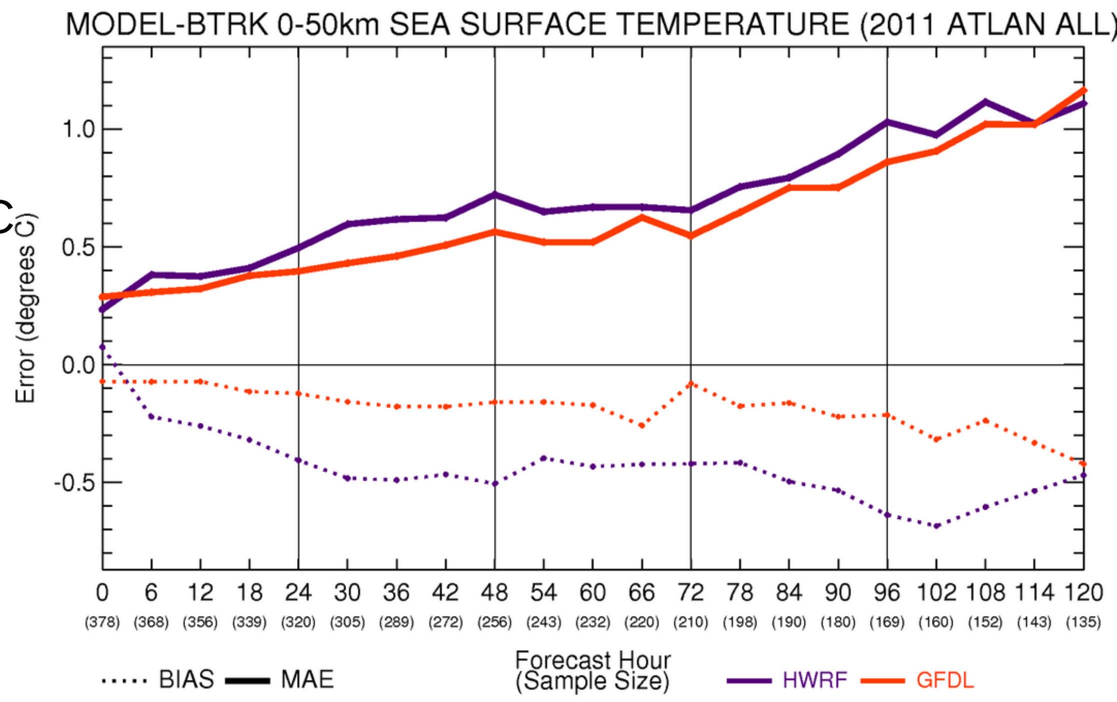


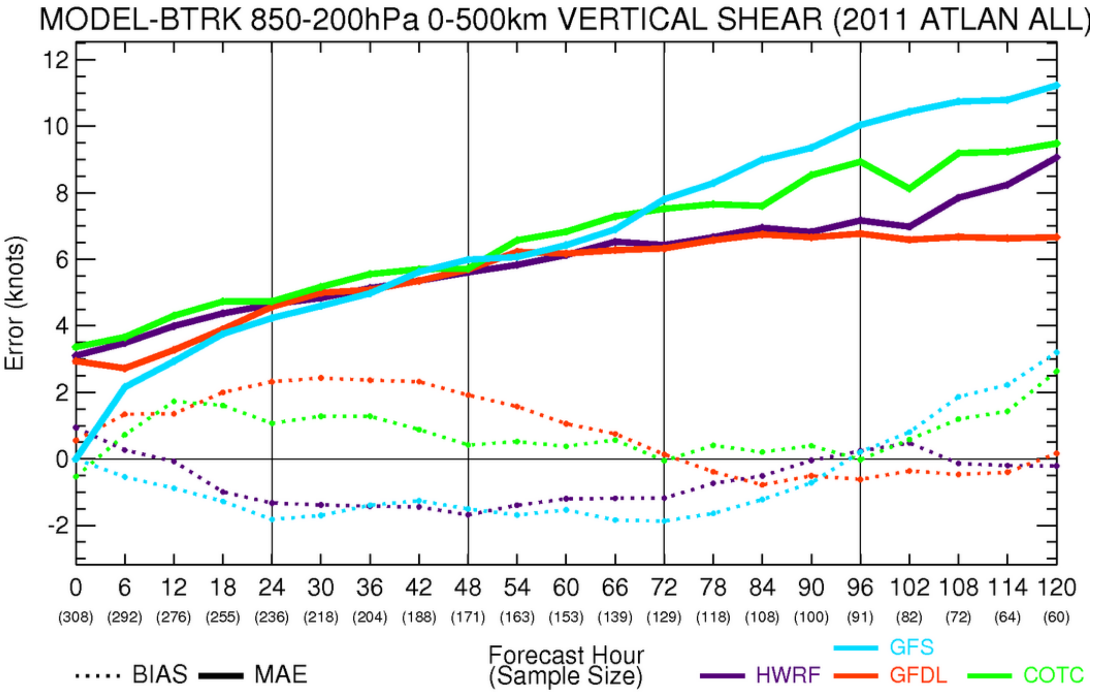
Excluding COTC





Excluding COTC





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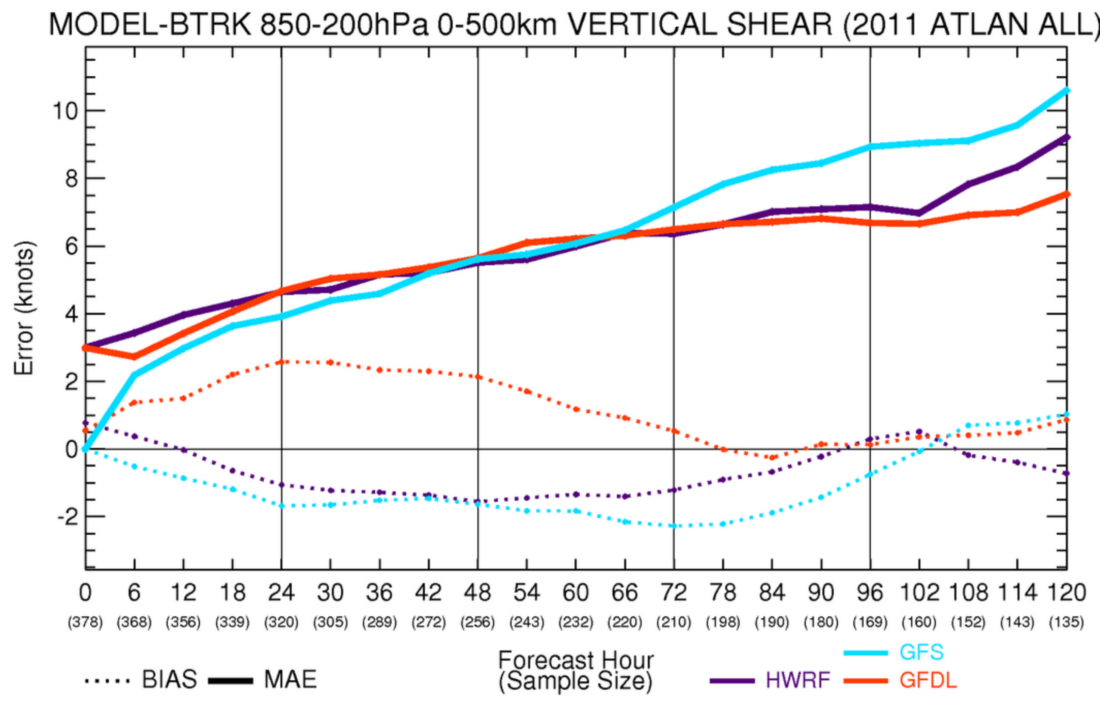

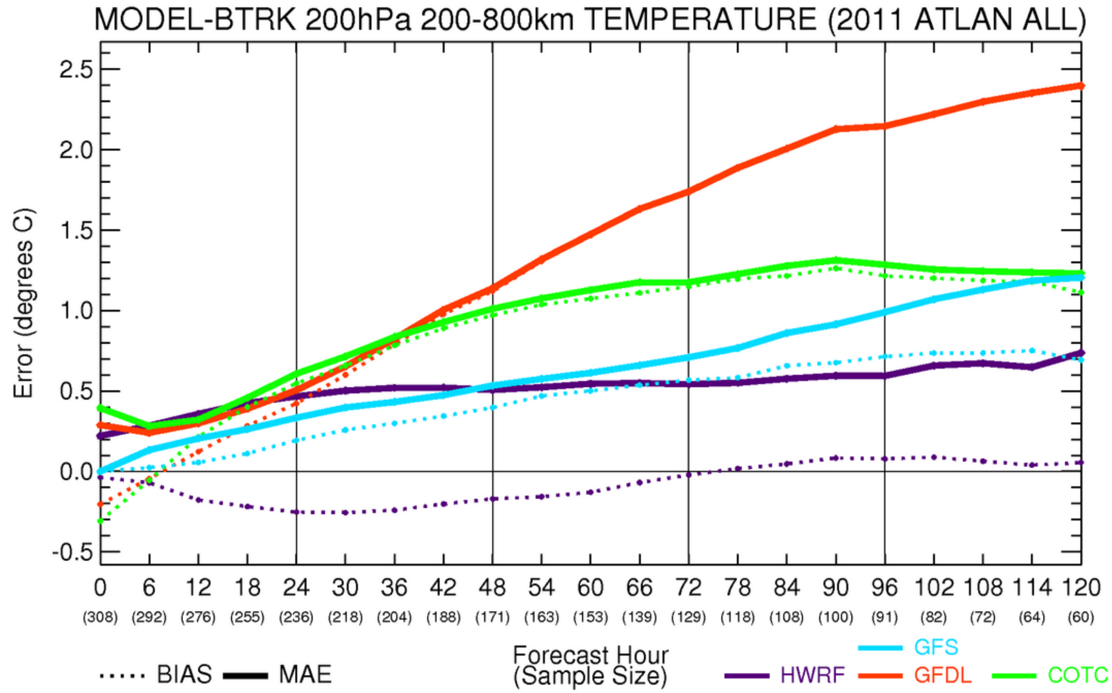

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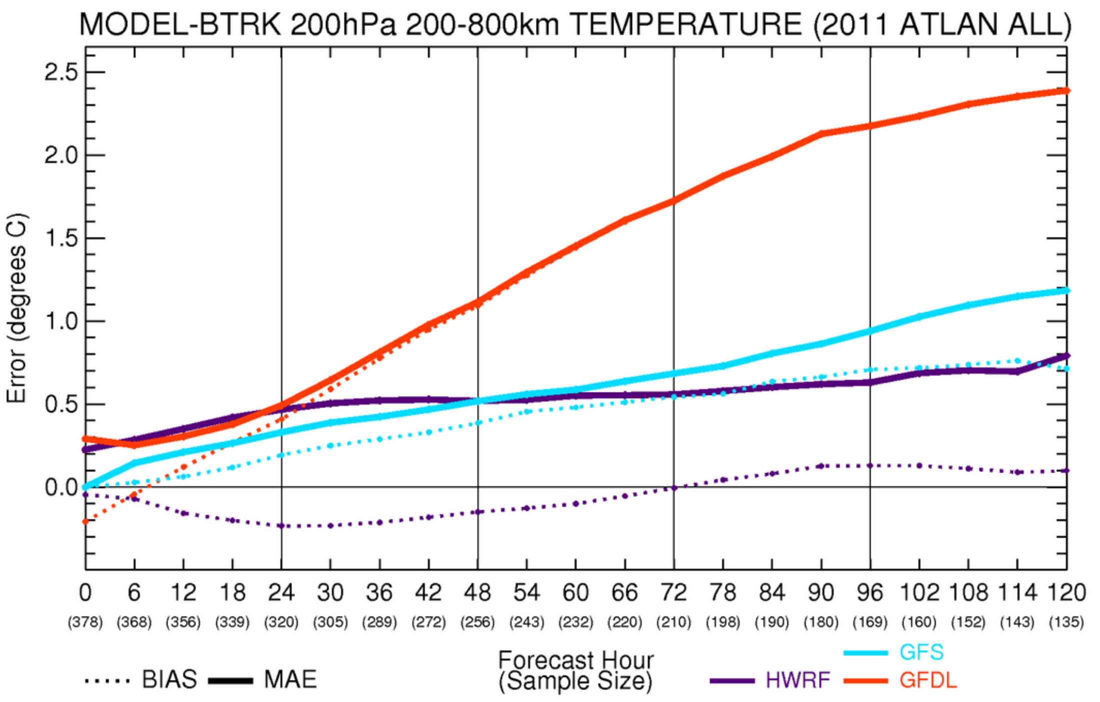

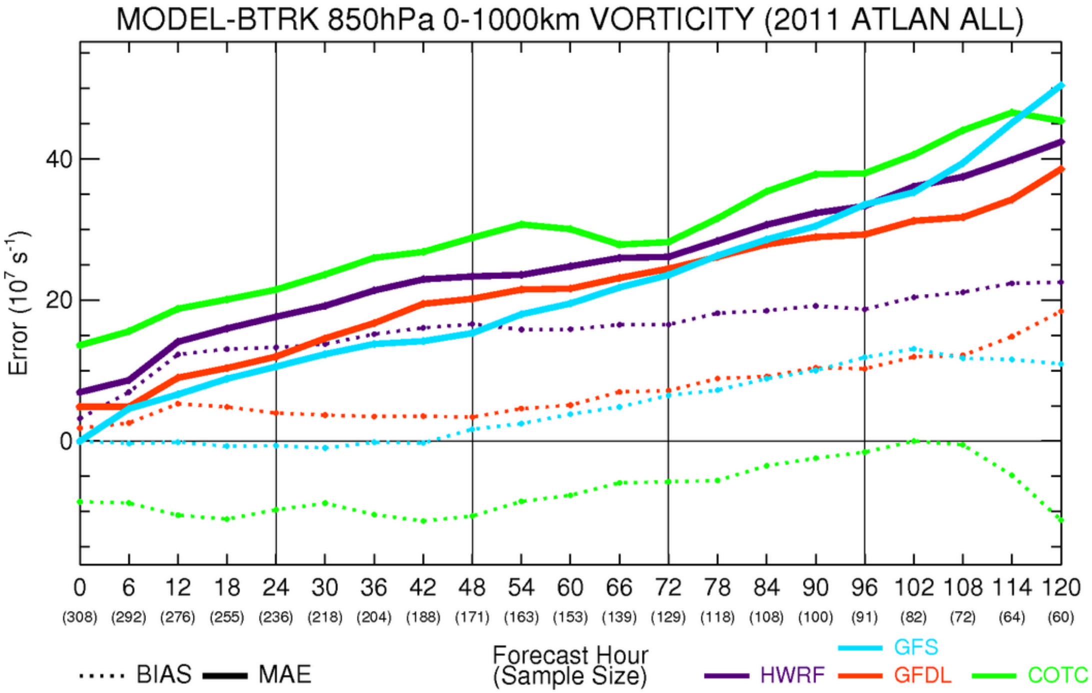

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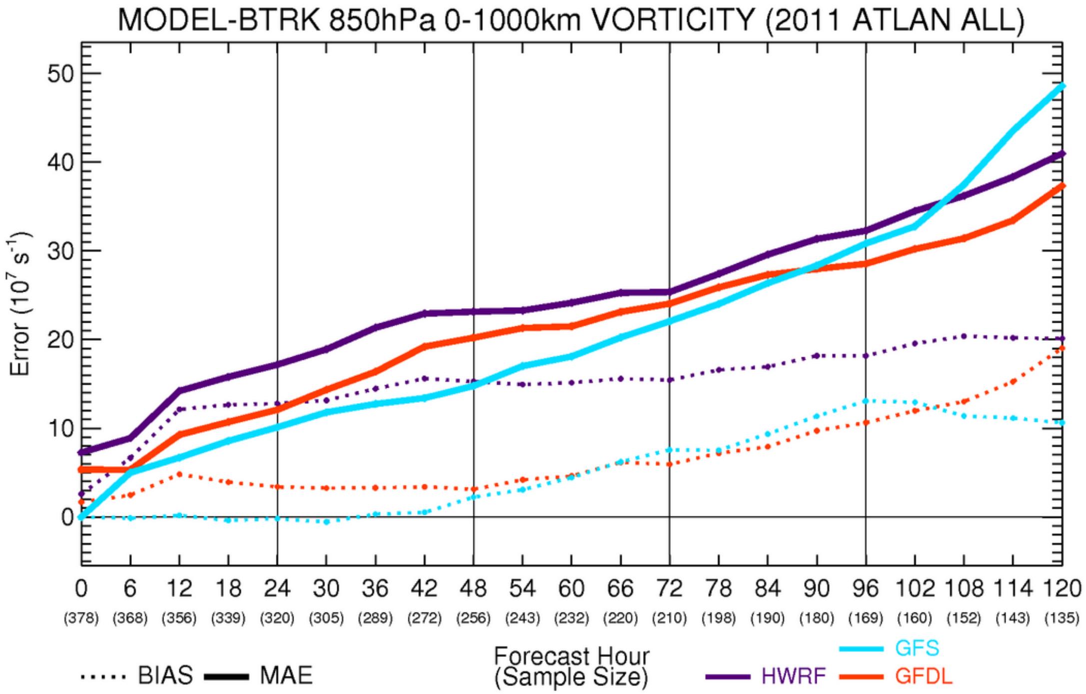

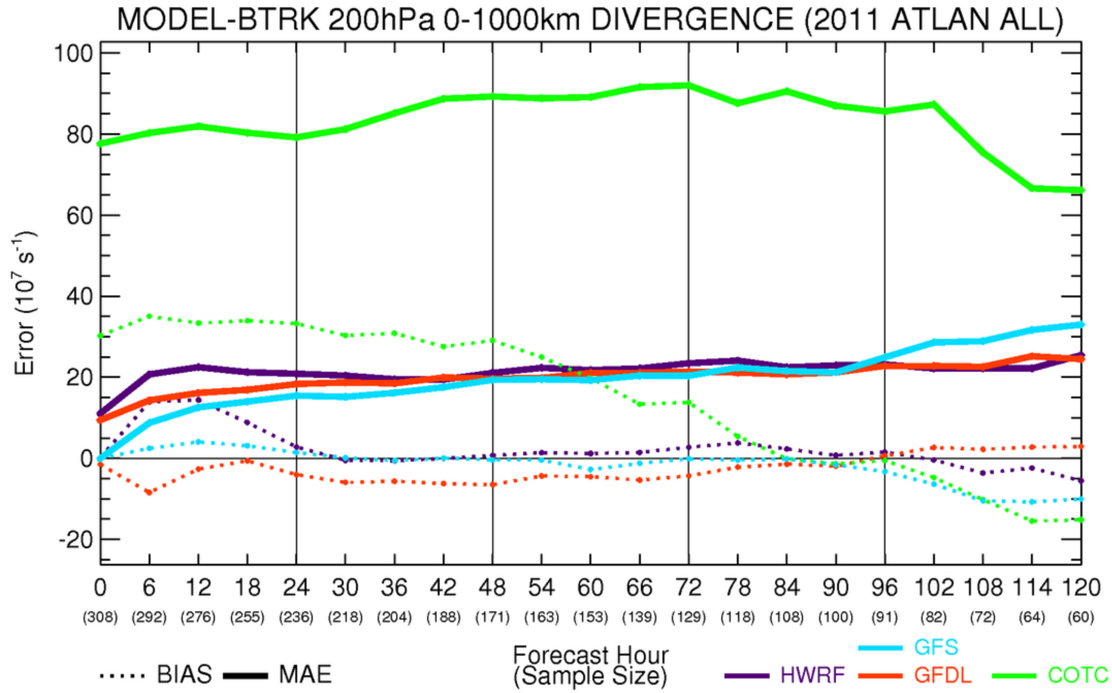

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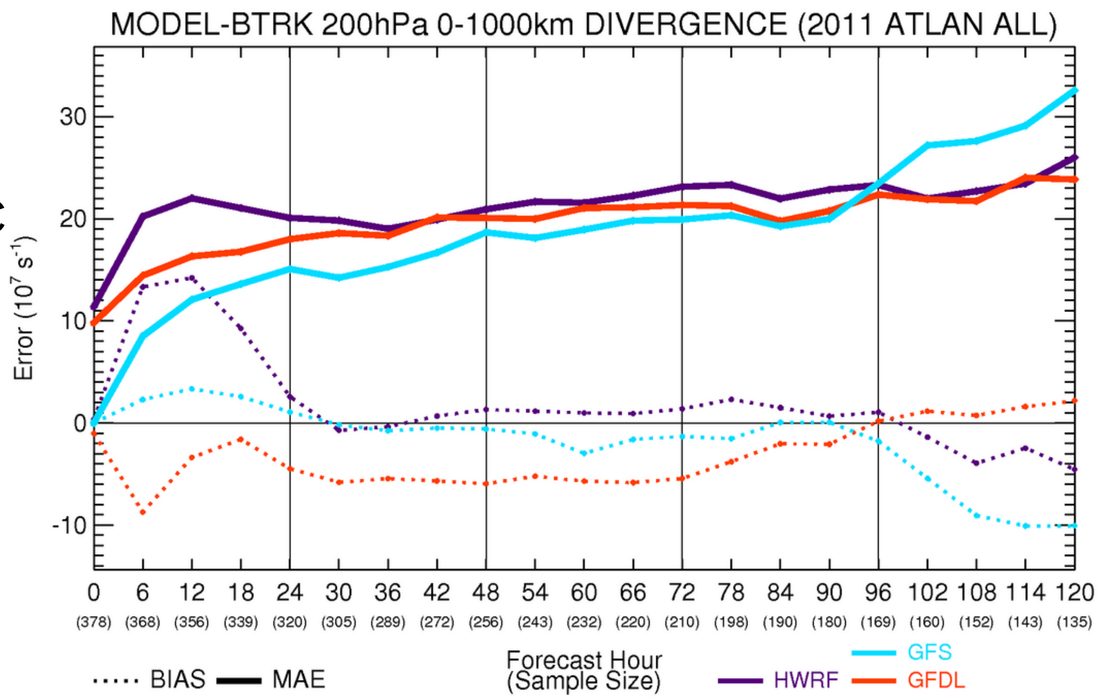

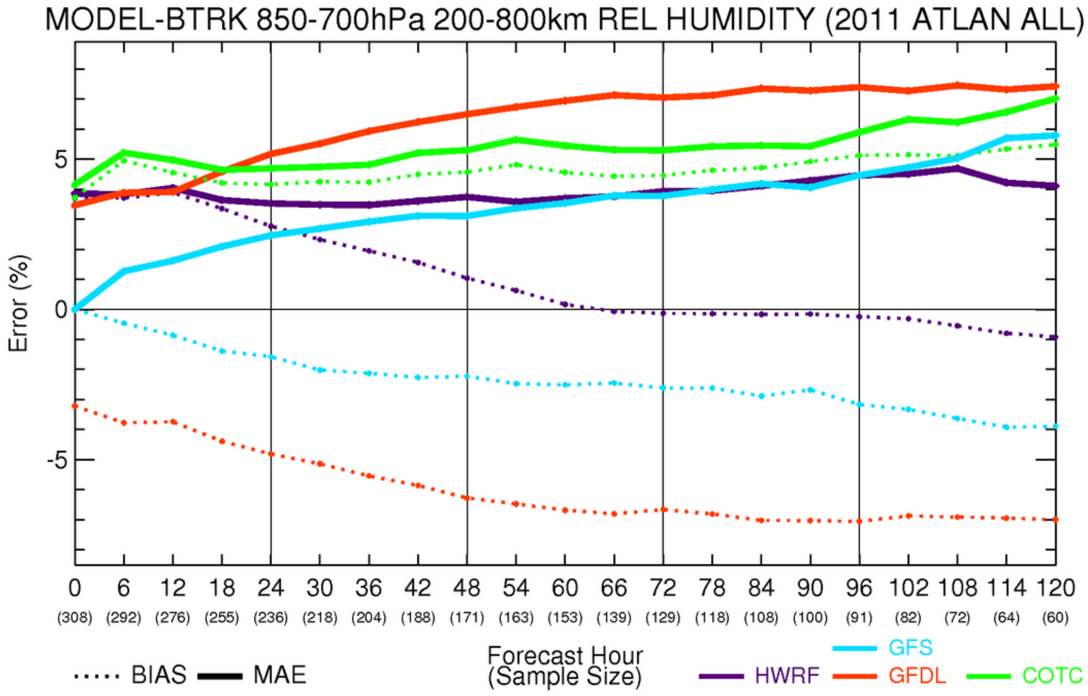

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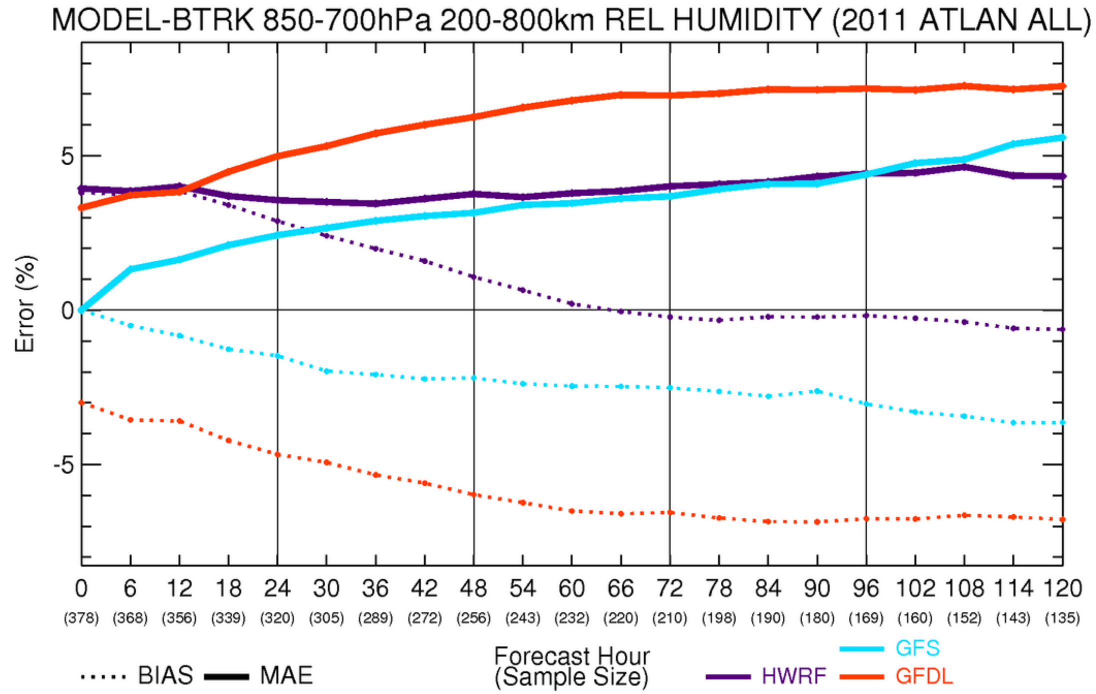

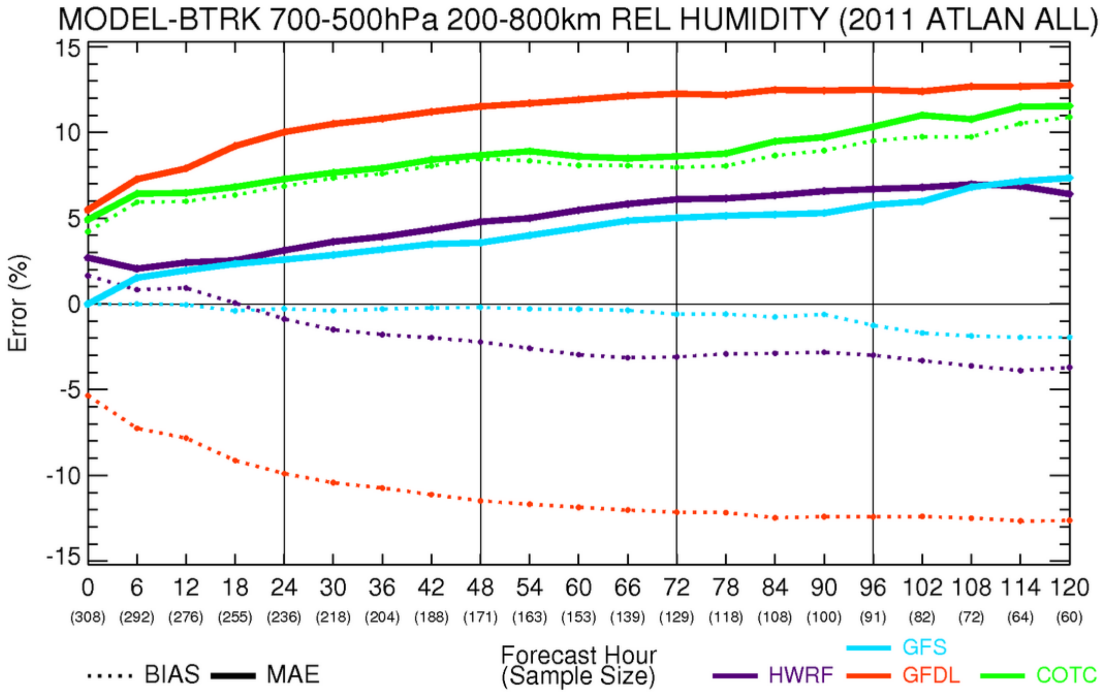

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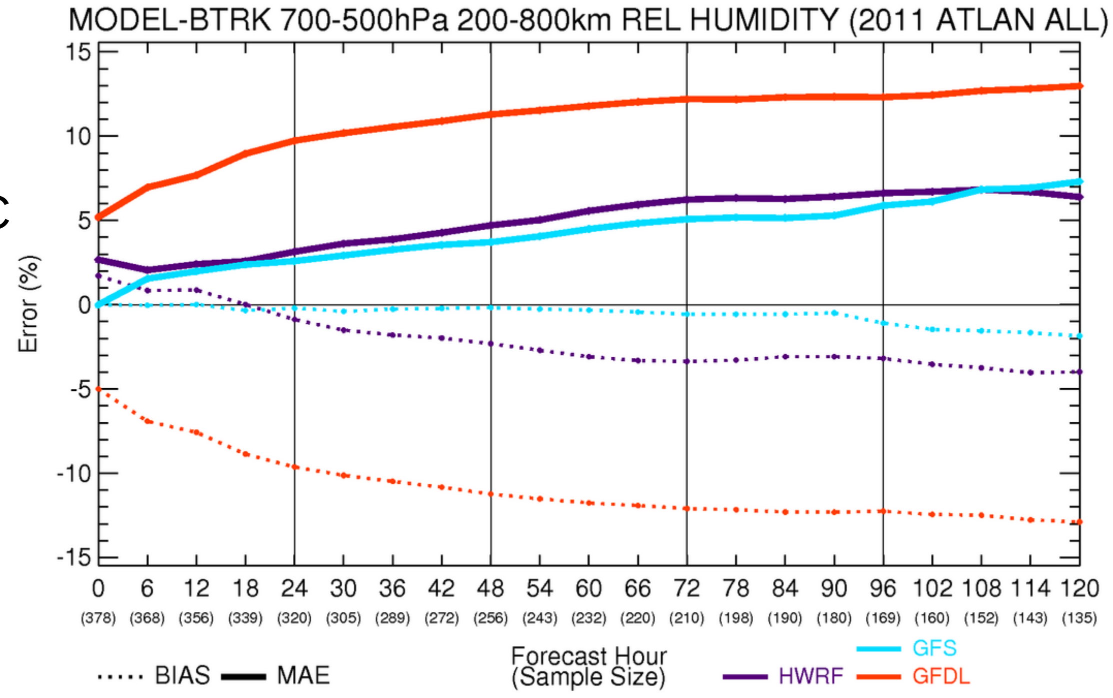
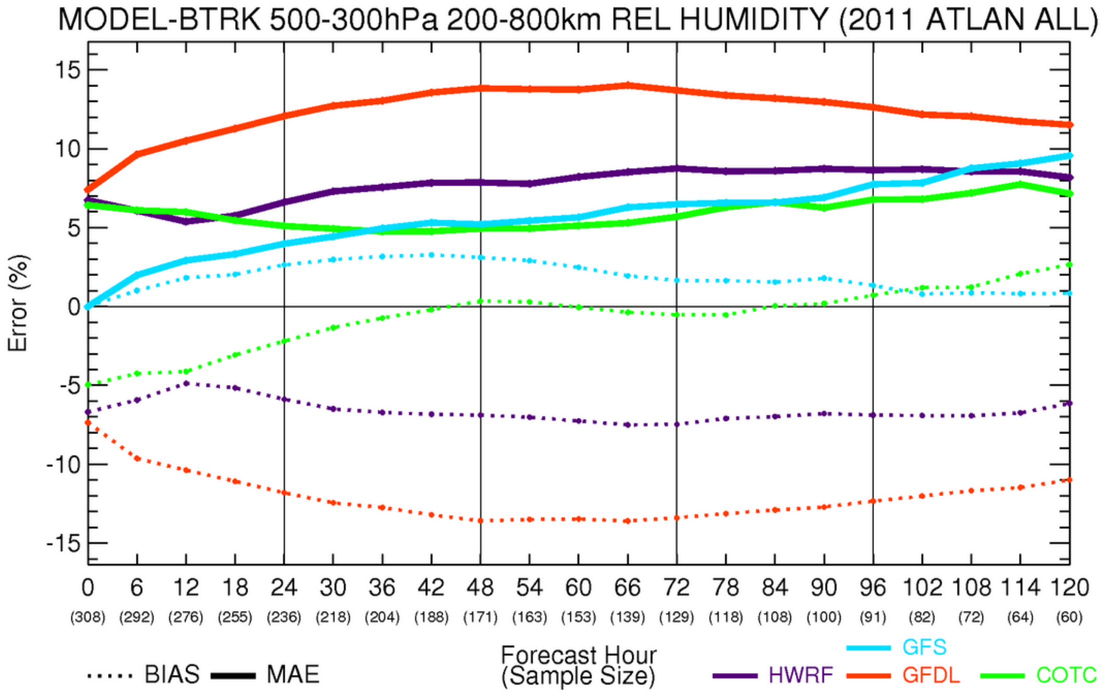
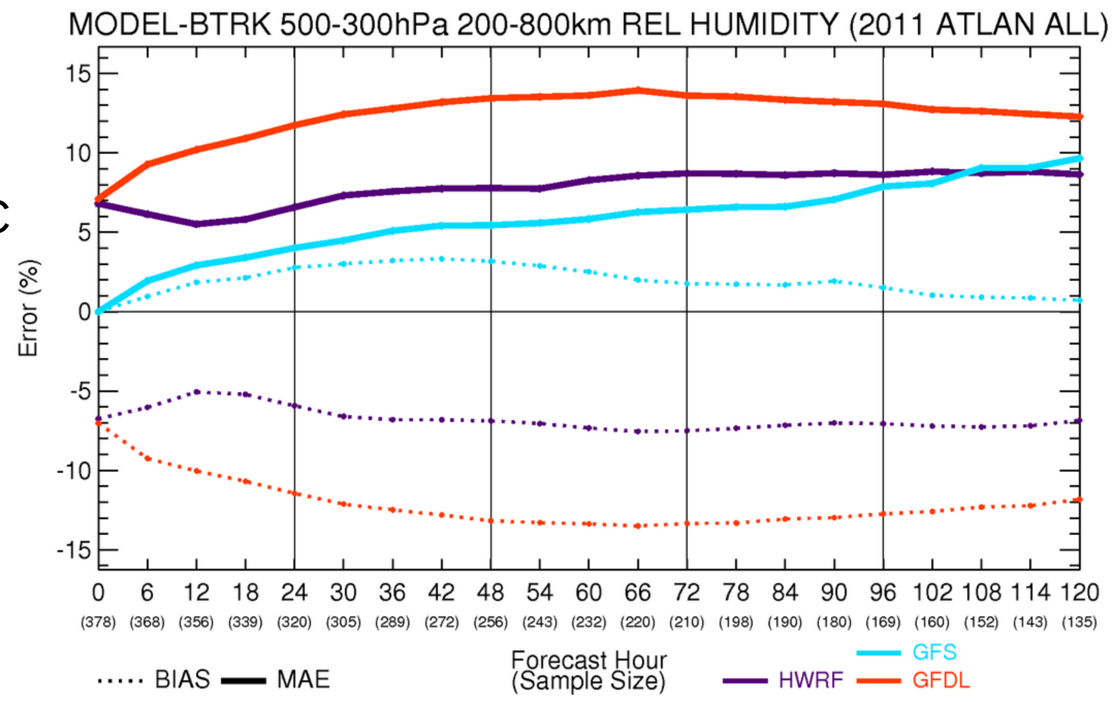
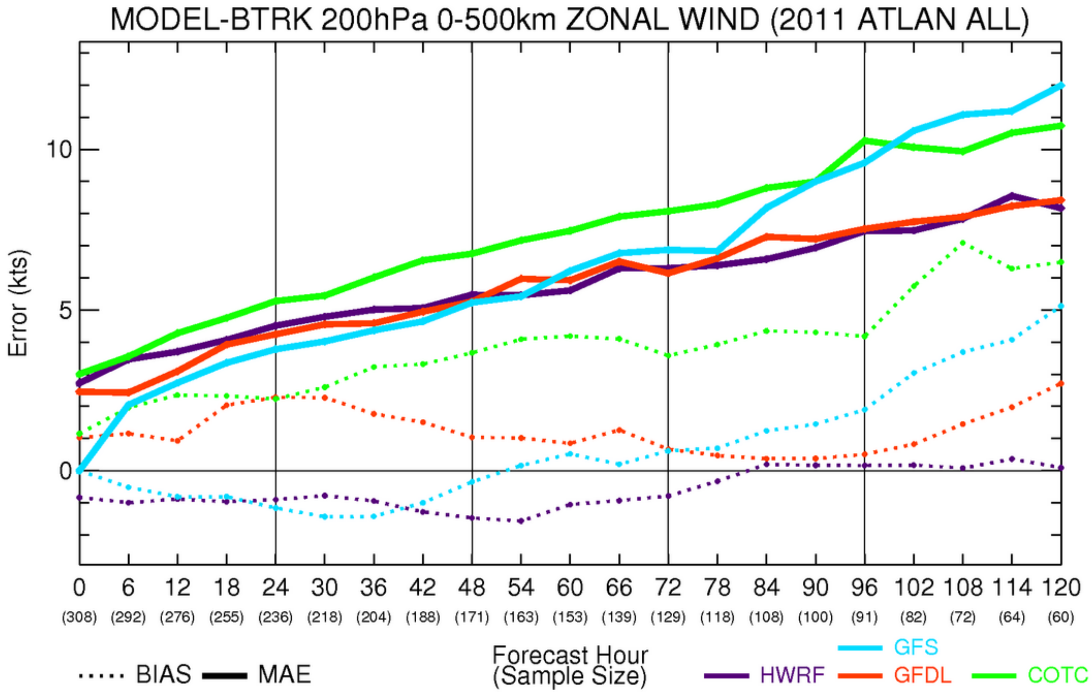


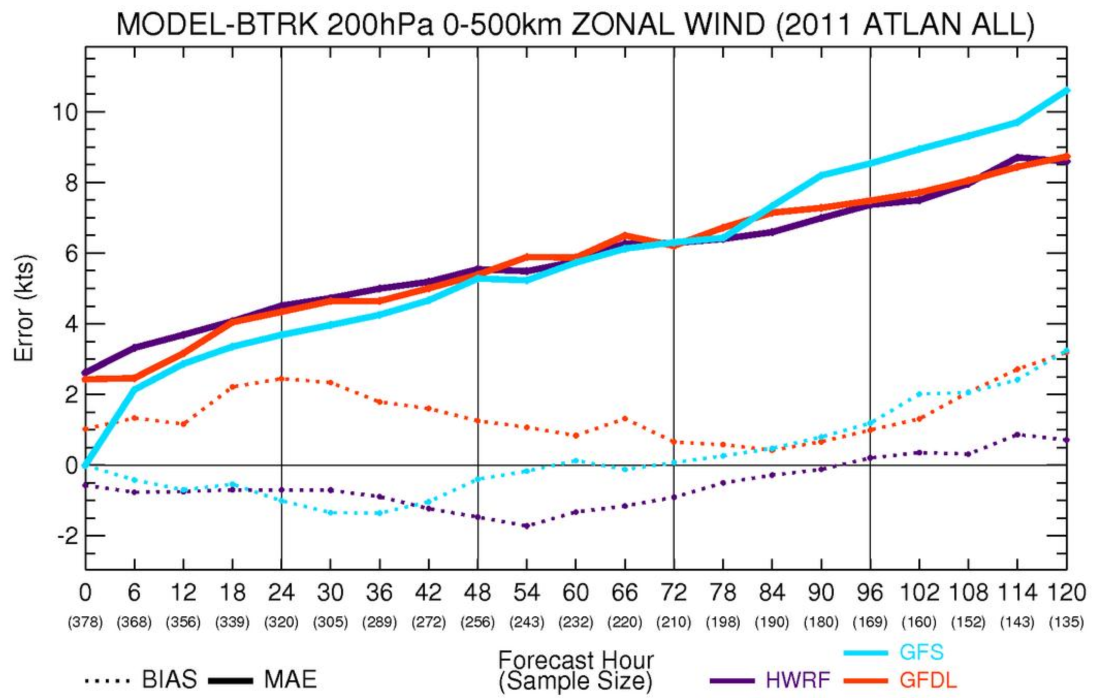


Excluding COTC





Excluding COTC



TCMT Input

Stream 1.5 and Stream 2.0 Model Performance Hurricane Maria (AL142011)

Christopher Williams and Paul Kucera

NCAR/RAL

Updated 20 October 2011

Introduction

- Intensity and track errors were computed for homogeneous sample for stream 1.5, stream 2.0 and several operational models
- Restricting all the model forecasts to a homogeneous sample resulted in very small sample sizes.
  - So, in addition to evaluating all the models together, we did the same analysis but excluded the model(s) that have small sample sizes.
- Note: Errors based on Working Best Track

INTENSITY

The following table shows which Operational (black), Stream 1.5 (red), and Stream 2.0 (blue) forecasts are available at each forecast time when the storm is classified as either tropical or subtropical.

The values in the ATCF ID columns reflect the last forecast hour/period for each available forecast. A blank space means no forecast is available.

STORM_AL14	DSHP	LGEM	HWFI	AHWI	GF5I	GHMI	SPC3	H3GI	A4NI	UWNI	GPMI	COTI	EMXI
2011090618	120	120	36		132					120			
2011090700	120	120	132	120	132	132	120	120	120				
2011090706	120	120	132	120	132	132	120	120	120				168
2011090712	120	120	132	120	132	132	120	120	120				
2011090718	120	120	132	120	132	132	120	120	120	108		12	168
2011090800	120	120	132	120	96	132	120	120	120	120			
2011090806	120	120	132	120	132	132	120	120	120	108		12	168
2011090812	120	120	132	120	132	132	120	120	120	84		12	
2011090818	120	120	132	120	132	132	120		120	120		12	60
2011090900	120	120	132	120	132	132	120		120	120			
2011090906	120	120	132	120	132	132	120		120	120			48
2011090912	120	120	132	120	132	132	120	120	120	120	120		
2011090918	120	120	132	120	132	132	120		120	120	120		168
2011091000	120	120	132	120	132	132	120	120	120	120	120		
2011091006	120	120	132	120	132	132		120	120	120			
2011091012	120	120	132	120	132	132	120	120	120	120	120	60	
2011091018	120	120	132	120	132	132	120	120	120	120	120		168
2011091100	120	120	132	120	132	132	120	120	120	120		12	
2011091106	120	120	132	120	132	132	120	120	120	120			
2011091112	120	120	132	120	132	132	120	120	120	48	120	120	
2011091118	120	120	120	120	120	132	120	120	120	108		120	144
2011091200	120	120	108	120	120	120	120		108	108	120	120	
2011091206	120	120	120	120	120	132	120	120	108	108	120	108	96
2011091212	120	120	108	120	108	108	120	108	108	108	108	108	
2011091218	120	120	108	120	108	108	120	108	96	96	108	120	84
2011091300	120	120	108	120	96	108	120	96	96	84	108	96	
2011091306	120	120	96	120	96	96	120	96		84	96	12	72
2011091312	120	120	96	120	96	96	120	96		84	96		
2011091318	120	120	84	120	84	96	120	84			84	72	48
2011091400	120	120	84	120	84	84	120	84			84		
2011091406	120	120	72	120	72	72	120	72			72	60	36
2011091412	120	120	72	120	72	72	120	72	60		84	60	
2011091418	120	108	72	120	72	72	120	60		60	72	48	12
2011091500	120	108	48	120	60	60	120	60	60	48	60	48	
2011091506	120	108	48	120	60	48	120	48	48	48	48	48	0
2011091512	120	108	48	120	36	36	120	48	36	48	48	36	
2011091518	120	96	48	120	36	36	120	48	36	36	36	36	0
2011091600	120	96	36	120	36	36	120	48	12	36	36		
2011091606	120	96	36	120	12	12	120	12	12	12	12		12
2011091612	96	84	36	120	12	12	120	12			12		
2011091618	60	0	36	120		0	120						
COUNT (fcsts)	41	41	41	40	40	40	39	34	32	32	25	22	17
SUM (hours)	4836	4644	4128	4800	4104	4044	4680	3192	3180	2976	2124	1332	1452

Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96
LGEM	0.0	1.5	1.5	1.0	1.5	2.5	-1.0	-6.5	-9.0
DSHP	0.0	1.5	3.5	5.5	8.5	11.5	9.0	2.0	-1.0
GHMI	0.0	8.5	16.5	25.5	33.5	35.5	24.5	23.5	24.0
GF5I	0.0	5.5	10.0	20.5	26.0	24.0	19.0	16.0	8.0
HWFI	0.0	8.5	18.0	26.5	30.0	29.5	23.5	9.0	7.0
EMXI	0.0	1.0	0.0	-4.0	-5.5	-5.0	-10.0	-14.0	1.0
GPMI	0.0	8.0	13.5	22.5	29.5	31.5	26.0	25.5	22.0
AHWI	0.0	3.0	20.5	38.0	45.0	49.0	37.5	11.5	-1.0
COTI	0.0	11.0	19.0	21.5	22.5	25.0	17.0	8.5	7.0
UWNI	0.0	8.5	15.0	19.5	25.5	25.5	19.5	14.5	12.0
SPC3	0.0	1.5	3.0	3.0	3.5	3.0	-2.0	-10.0	-12.0
H3GI	0.0	9.0	15.5	21.0	21.0	22.0	18.0	-0.5	-12.0
A4NI	0.0	7.0	11.0	15.5	24.0	29.0	26.0	17.5	2.0
# Cases	4	2	2	2	2	2	2	2	1

All Stream 1.5 Models (Intensity) and requested baselines/models

Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
LGEM	0.0	1.4	4.0	2.8	3.2	4.0	2.8	-0.5	0.0	2.0	2.0
DSHP	0.0	0.4	5.7	7.7	11.0	13.3	12.7	9.0	7.2	7.5	5.0
GHMI	0.0	3.6	12.2	21.3	31.5	35.2	31.8	31.2	33.2	38.5	29.0
GF5I	0.0	1.7	8.7	15.2	19.7	23.3	20.8	17.3	14.2	12.8	26.0
HWFI	0.0	2.3	7.2	10.3	16.7	20.5	19.0	12.3	9.4	6.0	32.0
EMXI	0.0	0.7	2.5	1.2	0.2	-1.3	-5.2	-9.5	-7.6	-12.8	-25.0
AHWI	0.0	2.4	16.8	27.2	36.3	44.8	46.0	34.7	32.2	30.5	-3.0
UWNI	0.0	6.0	14.5	16.7	20.5	20.5	16.8	10.3	5.2	-1.2	12.0
SPC3	0.0	0.9	4.3	4.2	5.0	4.8	2.7	-2.3	-2.0	0.0	-6.0
H3GI	0.0	3.7	11.7	16.0	18.0	20.2	22.5	18.0	18.8	23.2	26.0
A4NI	0.0	5.1	10.3	15.5	22.0	27.0	26.3	20.5	13.6	7.8	32.0
# Cases	9	7	6	6	6	6	6	6	5	4	1

Excludes GPMI and COTI

Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
LGEM	-0.5	0.4	1.2	1.6	2.2	3.3	3.7	3.2	4.7	7.5	6.5
DSHP	-0.5	0.9	4.8	8.3	12.0	15.0	15.5	14.6	14.5	14.3	11.7
GHMI	-0.5	3.7	7.2	16.5	27.2	32.5	33.9	34.2	36.6	40.0	37.7
GF5I	-0.5	2.2	6.1	14.5	19.4	24.4	25.6	22.2	21.4	26.4	32.8
HWFI	-0.5	0.2	1.1	5.8	12.7	18.3	20.1	17.9	18.9	20.4	27.0
AHWI	-0.5	-2.5	9.3	22.1	32.5	40.8	43.4	38.1	32.7	28.7	10.3
UWNI	-0.5	7.7	14.4	19.0	24.2	25.3	22.5	17.1	15.9	13.3	18.0
SPC3	-0.5	0.0	2.0	3.2	4.2	4.6	3.7	1.7	1.9	3.6	-0.5
H3GI	-0.5	2.8	8.7	15.3	18.8	21.9	24.7	23.0	23.3	26.3	26.2
A4NI	-0.5	3.7	6.2	11.9	19.6	24.9	28.3	26.3	24.0	18.0	23.3
# Cases	22	22	20	18	16	15	15	15	13	10	6

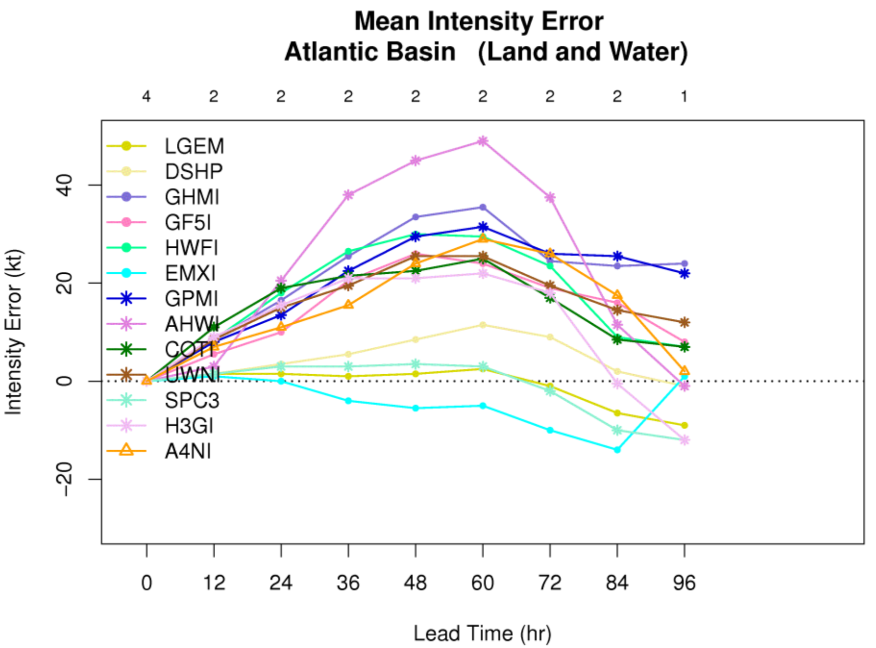
Excludes EMXI, GPMI, and COTI

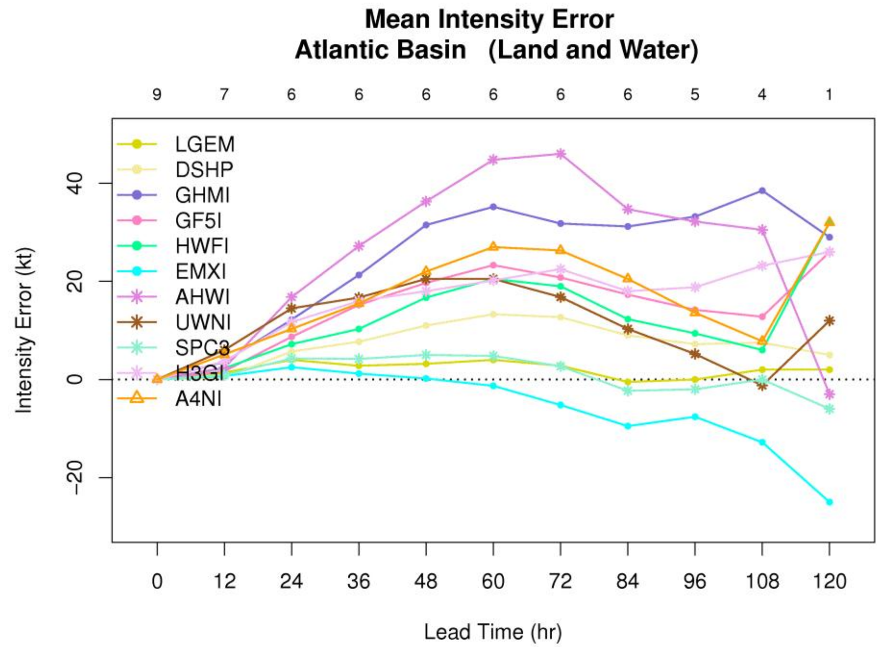
Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

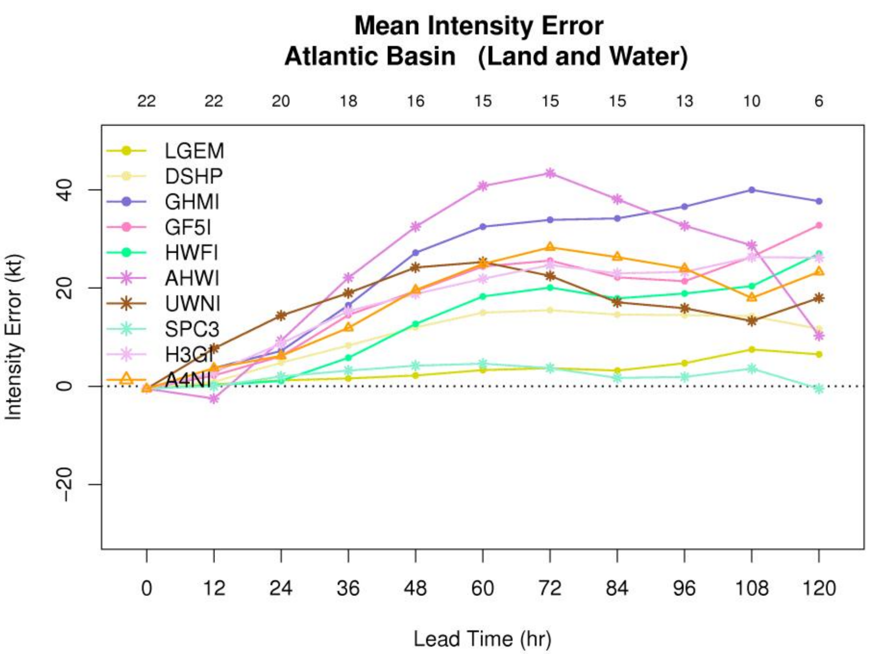
	0	12	24	36	48	60	72	84	96	108	120
LGEM	-0.3	-0.2	0.1	0.3	-0.0	0.8	2.0	2.8	3.3	4.5	3.6
DSHP	-0.3	0.5	3.8	7.1	9.9	12.5	13.8	13.6	13.4	12.3	9.7
GHMI	-0.3	2.4	4.2	10.9	19.0	24.7	29.5	32.2	35.6	38.9	43.2
GF5I	-0.3	1.1	3.4	9.9	12.3	17.5	21.5	19.9	16.8	18.1	15.9
HWFI	-0.3	-0.4	-1.0	1.7	6.0	10.6	14.0	13.9	12.2	9.2	4.3
AHWI	-0.3	-4.8	7.8	21.2	27.0	33.1	37.6	37.8	36.5	32.7	25.1
SPC3	-0.6	-1.1	0.1	0.9	0.8	1.0	1.2	0.8	0.6	0.5	-0.6
H3GI	-0.3	2.1	6.1	11.2	12.9	16.6	18.7	19.8	22.1	22.6	20.6
# Cases	33	32	30	28	26	24	22	20	18	15	14

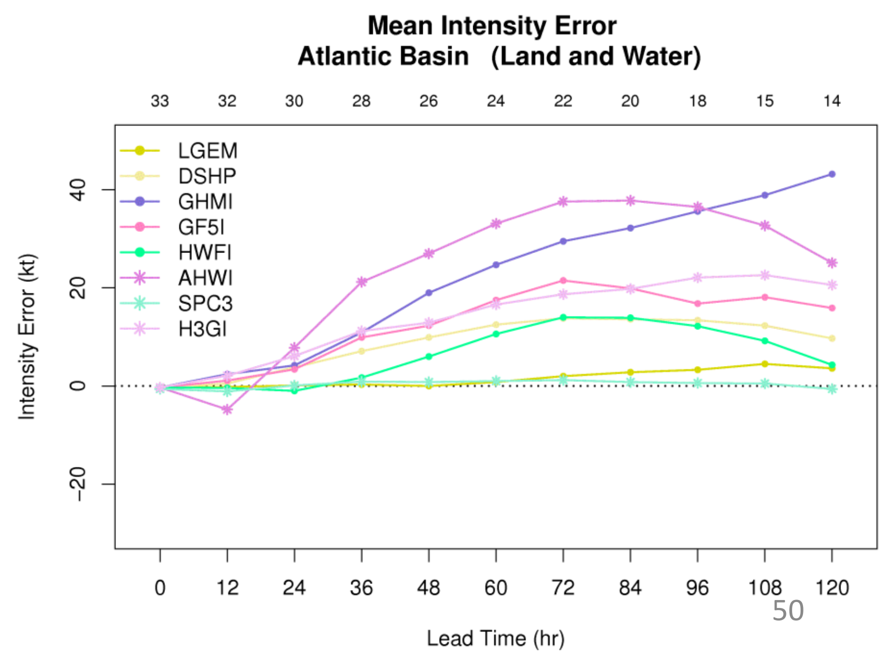
Excludes EMXI, GPMI, COTI, UWNI, and A4NI

Homogeneous Comparison of Stream 1.5 and Stream 2.0 Models - Maria









Absolute Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96
LGEM	0.0	3.5	3.5	6.0	3.5	6.5	9.0	8.5	9.0
DSHP	0.0	3.5	3.5	6.5	8.5	11.5	9.0	8.0	1.0
GHMI	0.0	8.5	16.5	25.5	33.5	35.5	24.5	23.5	24.0
GF5I	0.0	5.5	10.0	20.5	26.0	24.0	19.0	16.0	8.0
HWFI	0.0	8.5	18.0	26.5	30.0	29.5	23.5	14.0	7.0
EMXI	0.0	3.0	4.0	6.0	5.5	6.0	10.0	14.0	1.0
GPMI	0.0	8.0	13.5	22.5	29.5	31.5	26.0	25.5	22.0
AHWI	0.0	4.0	20.5	38.0	45.0	49.0	37.5	17.5	1.0
COTI	0.0	11.0	19.0	21.5	22.5	25.0	17.0	8.5	7.0
UWNI	0.0	8.5	15.0	19.5	25.5	25.5	19.5	14.5	12.0
SPC3	0.0	3.5	4.0	6.0	3.5	6.0	8.0	10.0	12.0
H3GI	0.0	9.0	15.5	21.0	21.0	22.0	18.0	8.5	12.0
A4NI	0.0	7.0	11.0	15.5	24.0	29.0	26.0	17.5	2.0
# Cases	4	2	2	2	2	2	2	2	1

All Stream 1.5 Models (Intensity) and requested baselines/models

Absolute Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
LGEM	0.0	4.9	8.0	7.5	4.5	5.3	8.8	7.2	6.0	6.0	2.0
DSHP	0.0	4.7	7.3	8.7	11.0	13.3	12.7	11.0	7.6	10.0	5.0
GHMI	0.0	5.3	12.2	21.3	31.5	35.2	31.8	31.2	33.2	38.5	29.0
GF5I	0.0	4.3	8.7	15.2	19.7	23.3	20.8	21.0	19.8	17.8	26.0
HWFI	0.0	5.7	8.2	13.0	20.0	21.2	22.0	19.7	18.2	15.0	32.0
EMXI	0.0	4.7	5.8	6.8	5.8	5.3	7.5	10.2	8.0	12.8	25.0
AHWI	0.0	4.4	16.8	27.2	36.3	44.8	46.0	36.7	32.6	32.5	3.0
UWNI	0.0	6.9	14.5	16.7	20.5	21.8	21.5	19.7	18.4	17.2	12.0
SPC3	0.0	4.9	8.0	7.8	5.0	5.8	8.3	7.0	5.6	5.0	6.0
H3GI	0.0	5.4	11.7	16.0	18.0	20.2	22.5	21.0	23.6	24.8	26.0
A4NI	0.0	6.0	10.3	15.5	22.0	27.0	26.3	23.8	19.6	15.2	32.0
# Cases	9	7	6	6	6	6	6	6	5	4	1

Excludes GPMI and COTI

Absolute Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
LGEM	0.5	4.4	6.9	6.4	5.8	6.7	10.6	11.5	12.5	12.7	14.2
DSHP	0.5	4.4	7.3	9.7	12.0	15.0	15.5	16.2	16.3	16.9	13.7
GHMI	0.5	5.9	10.8	17.6	27.2	32.5	33.9	34.2	36.6	40.0	37.7
GF5I	0.5	5.4	10.8	15.1	20.3	25.7	27.6	27.9	28.9	30.6	32.8
HWFI	0.5	4.7	7.7	10.1	16.6	20.5	23.3	22.3	25.7	25.4	27.0
AHWI	0.5	6.7	12.3	22.3	32.5	40.8	43.4	39.9	38.2	31.7	19.7
UWNI	0.5	8.0	14.4	19.1	24.6	26.5	26.7	24.7	22.7	20.7	18.0
SPC3	0.5	4.1	6.9	6.1	5.3	6.3	9.2	10.0	10.8	9.4	13.2
H3GI	0.5	5.8	11.8	16.2	19.2	21.9	24.8	25.4	26.7	29.5	26.2
A4NI	0.5	4.8	7.5	11.9	20.2	25.1	28.3	27.7	26.3	27.4	24.7
# Cases	22	22	20	18	16	15	15	15	13	10	6

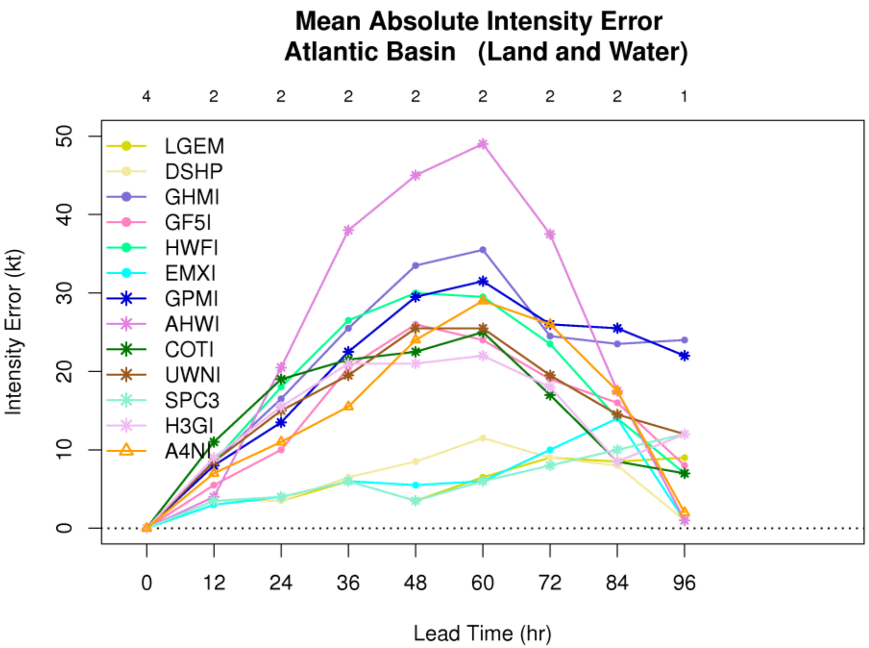
Excludes EMXI, GPMI, and COTI

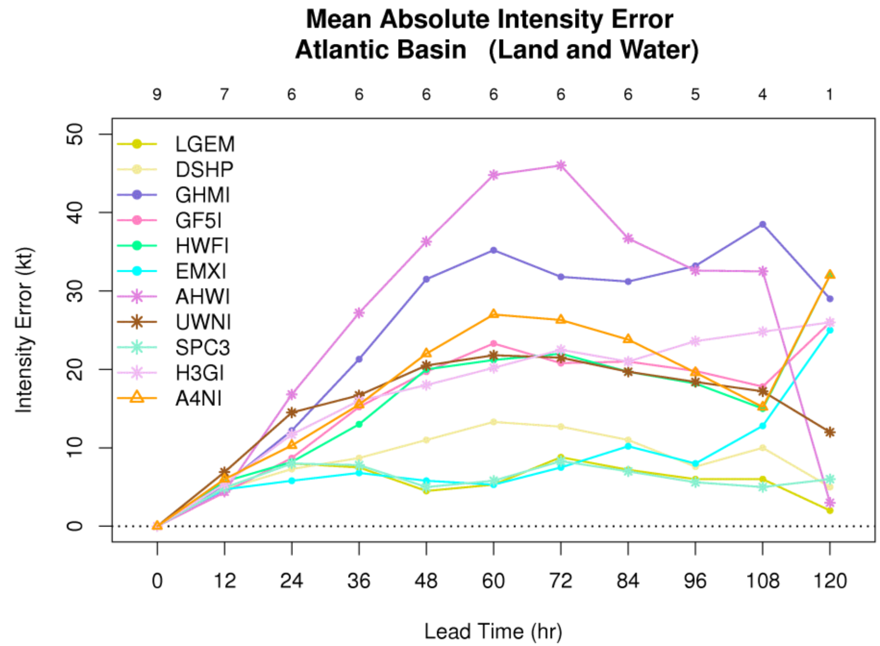
Absolute Mean Intensity Error (kt) for Homogeneous Sample (Land and Water)

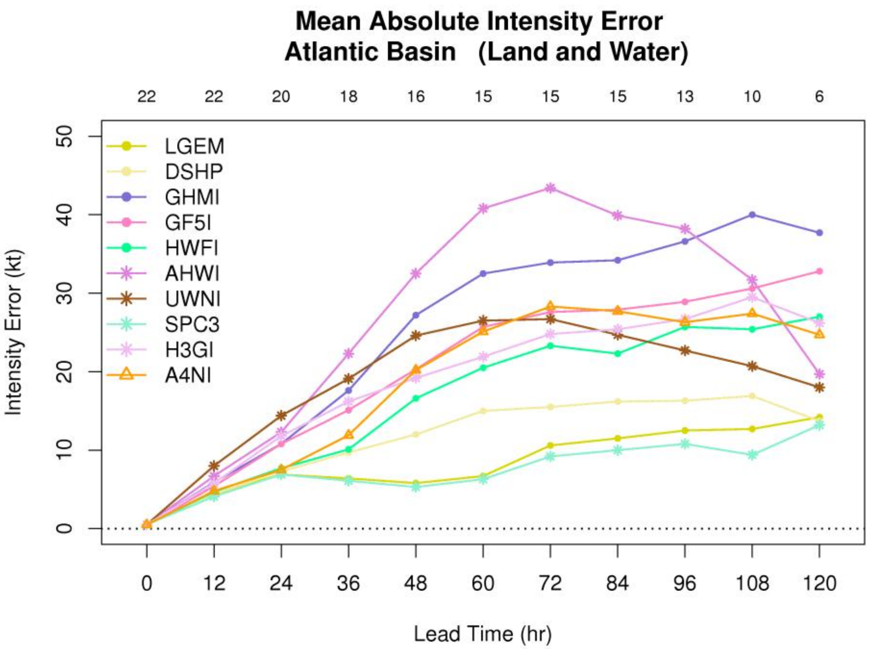
	0	12	24	36	48	60	72	84	96	108	120
LGEM	0.3	4.6	6.7	6.3	6.0	7.9	10.3	10.9	11.4	10.5	11.2
DSHP	0.3	4.3	7.0	8.6	9.9	12.7	13.8	14.8	14.9	14.1	13.1
GHMI	0.3	5.5	9.3	13.7	19.5	25.0	29.5	32.2	35.6	38.9	43.2
GF5I	0.3	5.3	9.4	11.9	14.0	18.8	22.9	24.2	22.9	22.5	21.8
HWFI	0.3	4.9	7.8	10.1	13.2	16.3	19.2	19.6	22.6	22.3	20.7
AHWI	0.3	8.0	11.0	21.4	27.2	33.8	38.9	40.0	40.5	34.7	34.1
SPC3	0.6	4.2	6.1	5.5	5.2	7.5	9.4	9.6	10.7	9.8	11.5
H3GI	0.3	5.4	9.5	13.2	15.3	16.9	20.2	22.2	24.7	24.7	26.1
# Cases	33	32	30	28	26	24	22	20	18	15	14

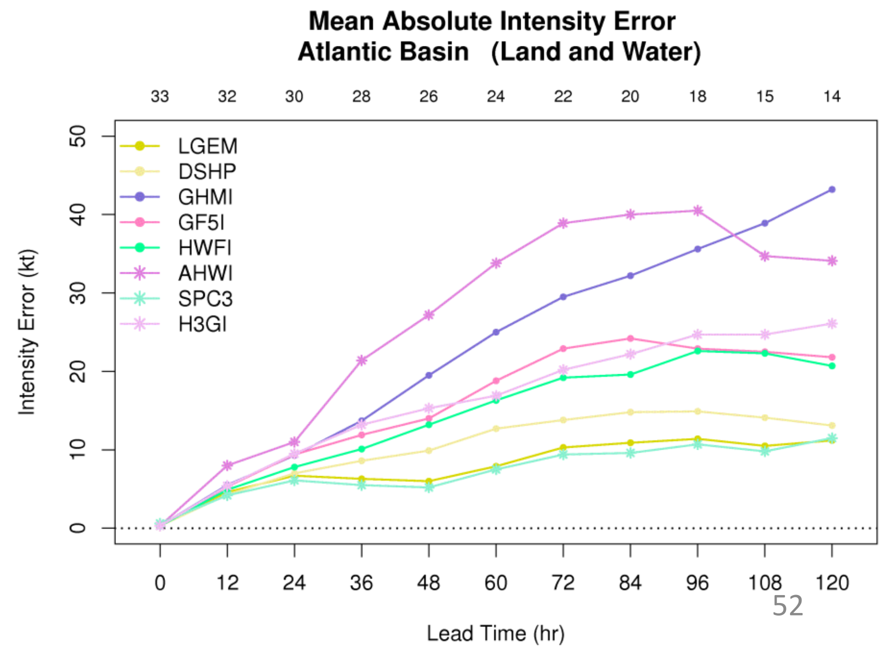
Excludes EMXI, GPMI, COTI, UWNI, and A4NI

Homogeneous Comparison of Stream 1.5 and Stream 2.0 Models - Maria









TRACK

The following table shows which Operational (black), Stream 1.5 (red), and Stream 2.0 (blue) forecasts are available at each forecast time when the storm is classified as either tropical or subtropical.

The values in the ATCF ID columns reflect the last forecast hour/period for each available forecast. A blank space means no forecast is available.

STORM_AL14	HWFI	GFSI	AHWI	GF5I	GHMI	H3GI	A4NI	G01I	GPMI	GTMI	FIMI	EMXI	NGMI
2011090618	36			132						120	120		
2011090700	132	168	120	132	132	120	120						
2011090706	132	168	120	132	132	120	120			120	120	168	120
2011090712	132	168	120	132	132	120	120						
2011090718	132	168	120	132	132	120	120			120	120	168	
2011090800	132	168	120	96	132	120	120						
2011090806	132	168	120	132	132	120	120			120		168	120
2011090812	132	168	120	132	132	120	120						
2011090818	132	168	120	132	132		120			120	120	60	
2011090900	132	168	120	132	132		120						
2011090906	132	168	120	132	132		120			120	120	48	120
2011090912	132	168	120	132	132	120	120	120	120				
2011090918	132	168	120	132	132		120		120	120	120	168	
2011091000	132	168	120	132	132	120	120	120	120				
2011091006	132	168	120	132	132	120	120			120	120		120
2011091012	132	168	120	132	132	120	120	120	120				
2011091018	132	168	120	132	132	120	120	120	120	120	120	168	
2011091100	132	168	120	132	132	120	120						
2011091106	132	168	120	132	132	120	120			120	120		120
2011091112	132	168	120	132	132	120	120	120	120				
2011091118	120	168	120	120	132	120	120	120		120	120	144	
2011091200	108	132	120	120	120		108		120				
2011091206	120	144	120	120	132	120	108	120	120	120	120	96	108
2011091212	108	132	120	108	108	108	108	108	108				
2011091218	108	132	120	108	108	108	96	108	108	120	120	84	
2011091300	108	168	120	96	108	96	96	108	108				
2011091306	96	132	120	96	96	96		96	96	120	120	72	84
2011091312	96	108	120	96	96	96		96	96				
2011091318	84	108	120	84	96	84		84	84			48	
2011091400	84	84	120	84	84	84		84	84				
2011091406	72	168	120	72	72	72		72	72			36	60
2011091412	72	72	120	72	72	72	60	72	84				
2011091418	72	72	120	72	72	60		60	72			12	
2011091500	48	72	120	60	60	60	60	60	60				
2011091506	48	60	120	60	48	48	48	60	48	120	120	0	12
2011091512	48	72	120	36	36	48	36	48	48				
2011091518	48	72	120	36	36	48	36	36	36	72	108	0	
2011091600	36	60	120	36	36	48	12	36	36				
2011091606	36	36	120	12	12	12	12	12	12	60	60	12	
2011091612	36	48	120	12	12	12			12				
2011091618	36	48	120		0					48	120		
COUNT (fcsts)	41	40	40	40	40	34	32	25	25	18	17	17	9
SUM (hours)	4128	5280	4800	4104	4044	3192	3180	2220	2124	1980	1968	1452	864

Mean Track Error (nm) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
GFSI	14.7	36.0	38.0	62.0	67.5	108.0	131.5	133.0	143.0	260.0	331.0
GHMI	14.7	41.5	52.5	91.0	113.5	163.5	193.0	183.5	219.0	415.0	504.0
GF5I	14.7	51.5	61.0	107.0	145.5	200.0	229.0	235.5	261.0	270.0	331.0
HWFI	14.7	61.5	89.0	136.0	173.0	222.5	236.0	233.0	246.5	127.0	177.0
EMXI	14.7	54.0	59.0	81.5	74.0	62.0	79.0	83.0	127.0	146.0	158.0
AHWI	14.7	65.0	112.5	194.5	255.5	309.0	343.5	374.5	382.5	221.0	200.0
FIMI	14.7	56.5	78.0	130.0	178.5	222.0	225.0	223.5	230.0	135.0	162.0
H3GI	14.7	66.5	96.5	145.5	179.5	213.5	256.0	284.5	306.5	142.0	215.0
A4NI	14.7	36.5	39.0	73.5	113.0	163.0	206.0	251.5	307.5	389.0	490.0
GTMI	14.7	56.5	71.5	110.0	136.0	172.5	190.0	193.5	183.5	109.0	158.0
NGMI	14.7	62.5	102.5	163.5	186.5	196.0	169.5	89.5	215.5	198.0	258.0
# Cases	3	2	2	2	2	2	2	2	2	1	1

Stream 1.5 Models (Track) and requested baselines/models except GPMI and G01I

Mean Track Error (nm) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
GFSI	9.6	33.6	57.0	70.2	83.3	99.8	137.2	188.7	207.8	279.2	319.8
GHMI	9.6	35.9	67.0	99.0	131.5	164.7	193.2	221.3	235.2	298.2	348.2
GF5I	9.6	37.1	68.7	106.2	142.3	179.3	210.3	236.3	311.2	387.8	477.8
HWFI	9.6	48.9	88.2	129.0	171.5	211.3	249.5	282.8	300.8	332.2	405.0
EMXI	9.6	41.3	78.8	111.8	130.5	134.7	147.7	145.7	186.8	203.2	175.5
AHWI	9.6	64.7	117.5	183.3	249.5	306.7	364.7	406.8	440.4	475.8	488.0
FIMI	9.6	40.3	76.7	111.8	151.0	177.3	198.7	212.0	259.0	269.0	306.2
H3GI	9.6	42.4	83.8	124.5	161.7	197.2	243.3	284.5	301.0	289.8	336.5
A4NI	9.6	28.9	51.2	78.7	113.5	148.3	197.7	245.7	321.0	386.5	442.0
GTMI	9.6	39.0	73.0	104.5	132.3	155.2	175.7	208.3	271.4	311.2	342.8
# Cases	9	7	6	6	6	6	6	6	5	4	4

Excludes GPMI, G01I, and NGMI

Mean Track Error (nm) for Homogeneous Sample (Land and Water)

	0	12	24	36	48	60	72	84	96	108	120
GFSI	7.7	35.5	60.5	90.6	113.1	123.4	119.9	161.2	230.9	272.7	304.0
GHMI	7.7	37.9	70.2	106.7	134.5	159.2	182.8	207.0	252.8	281.0	325.6
GF5I	7.7	36.5	69.5	112.9	145.1	158.4	195.1	248.6	307.2	379.7	466.0
HWFI	7.7	40.1	85.3	122.7	157.2	196.1	228.1	278.6	355.8	405.0	445.8
GPMI	7.7	32.6	64.3	104.9	136.9	146.4	164.9	201.0	227.4	250.2	299.6
G01I	7.7	46.7	80.8	118.2	147.6	169.3	196.4	225.6	268.6	329.2	358.6
AHWI	7.7	50.1	93.0	141.7	191.3	255.1	319.3	393.9	482.0	620.7	822.0
H3GI	7.7	39.8	85.4	124.1	172.1	214.3	252.3	286.7	323.4	317.5	303.6
# Cases	22	22	20	18	16	14	12	10	8	6	5

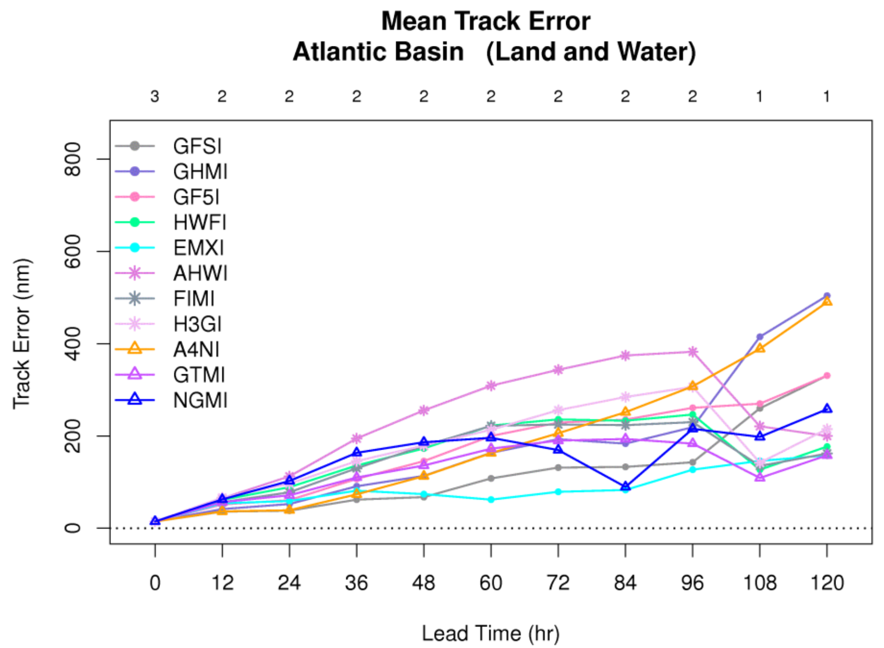
Excludes EMXI, FIMI, A4NI, GTMI, and NGMI

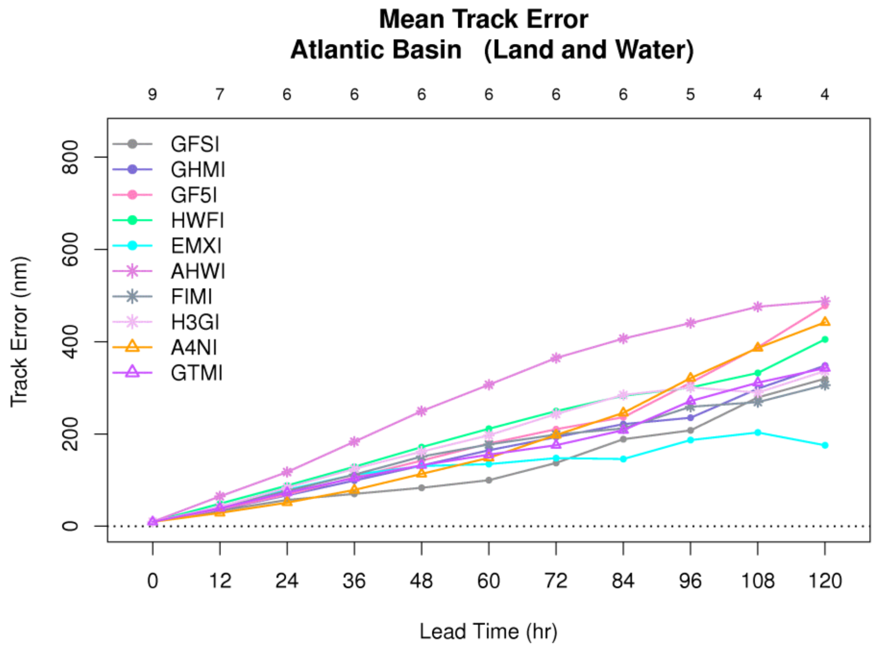
Mean Track Error (nm) for Homogeneous Sample (Land and Water)

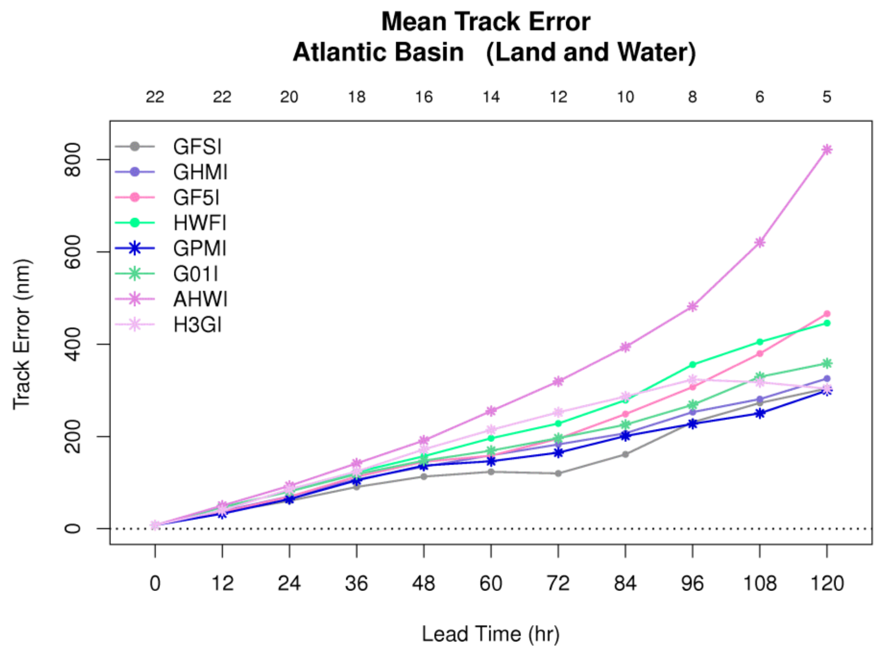
	0	12	24	36	48	60	72	84	96	108	120
GFSI	7.5	31.4	49.0	72.7	92.0	112.9	145.0	188.4	245.9	299.7	359.2
GHMI	7.5	35.9	66.4	105.9	147.5	190.3	227.2	265.0	304.5	335.1	380.9
GF5I	7.5	38.1	66.7	101.5	138.5	180.4	221.5	267.9	322.6	378.0	430.5
HWFI	7.5	41.6	79.2	109.8	141.2	173.1	209.2	255.5	299.5	343.9	360.4
AHWI	7.5	60.6	113.2	157.1	192.7	235.9	279.8	331.0	380.1	445.2	533.8
A4NI	7.5	30.1	43.6	63.2	89.1	125.1	170.8	224.6	286.3	351.6	396.4
# Cases	32	32	30	28	26	25	25	25	24	21	19

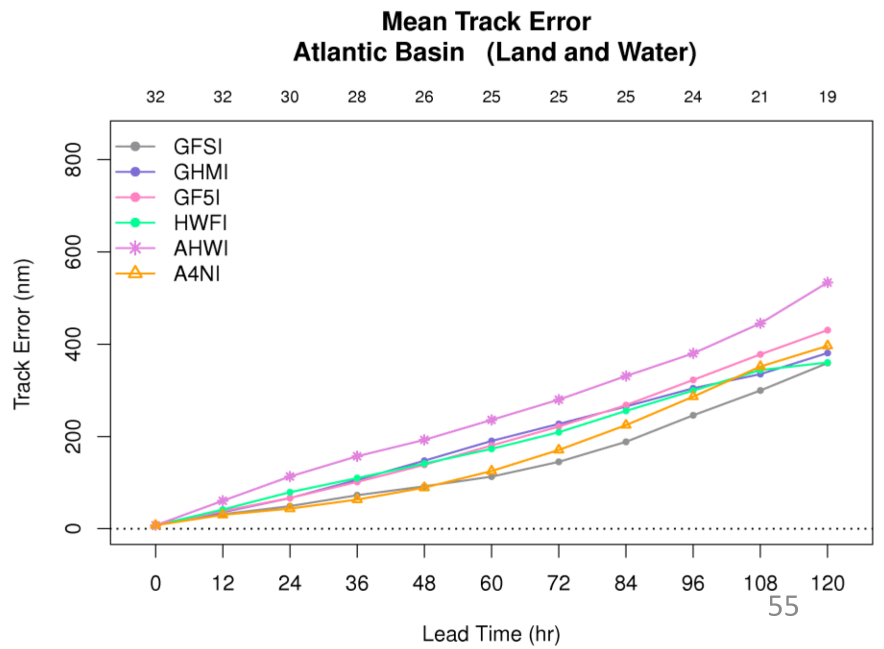
Excludes EMXI, GPMI, G01I, FIMI, H3GI, GTMI, and NGMI

Homogeneous Comparison of Stream 1.5 and Stream 2.0 Models - Maria









HRD Input

Inner-core diagnostics of HWRFx

Robert Rogers, Paul Reasor, Sylvie Lorsolo,
Jun Zhang, Dave Nolan, Frank Marks

Databases used in composites

Doppler database

40 radar analyses in 8 different storms

Storm name	Year	Best track intensity (kt)	Number of radar analyses
Guillermo	1997	105	4
Fabian	2003	110	3
Isabel	2003	140	7
Frances	2004	110-125	8
Ivan	2004	105	4
Katrina	2005	110-150	4
Rita	2005	125-145	6
Paloma	2008	125	4

GPS dropsonde database

794 dropsondes in 13 different storms

Storm name	Year	Best track intensity (kt)	Number of sondes
Erika	1997	83-110	40
Bonnie	1998	68-93	76
Georges	1998	66-78	39
Mitch	1999	145-155	28
Bret	1999	75-90	33
Dennis	1999	65-70	7
Floyd	1999	80-110	40
Fabian	2003	68-120	131
Isabel	2003	85-140	162
Frances	2004	68-83	62
Ivan	2004	65-135	123
Dennis	2005	65-70	7
Katrina	2005	68-100	46

HWRFx database

34 model output times in 16 runs of 5 different storms
3 km smallest grid length for all runs

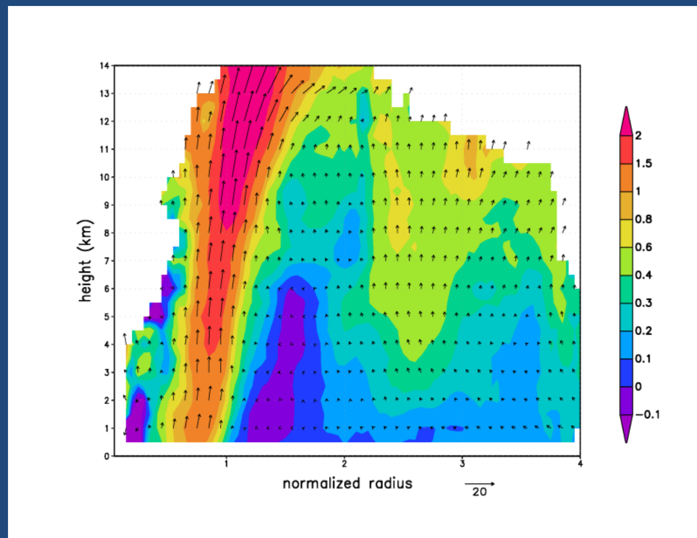
Storm name	Year	Simulated intensity (kt)	Number of output times
Wilma	2005	68-135	7
Rita	2005	98-145	8
Katrina	2005	68-130	8
Karl	2010	100-105	3
Earl	2010	105-120	8

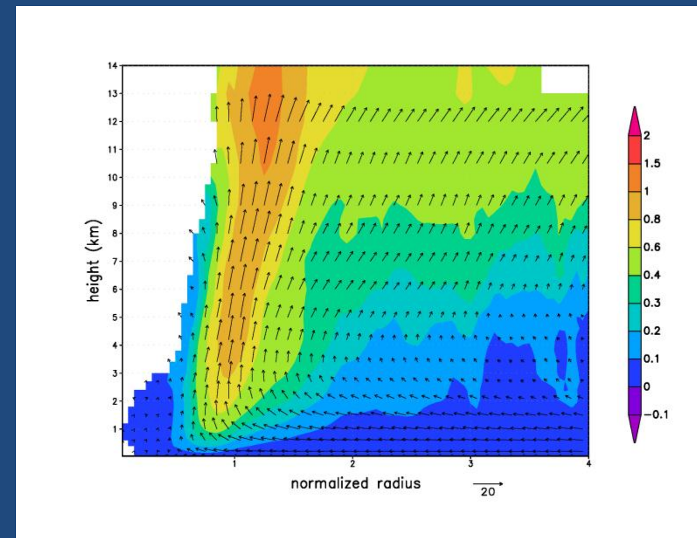
Eyewall vertical velocity

Examine multiple aspects of eyewall vertical velocity:
1) axisymmetric structure 2) asymmetric structure 3) full distribution

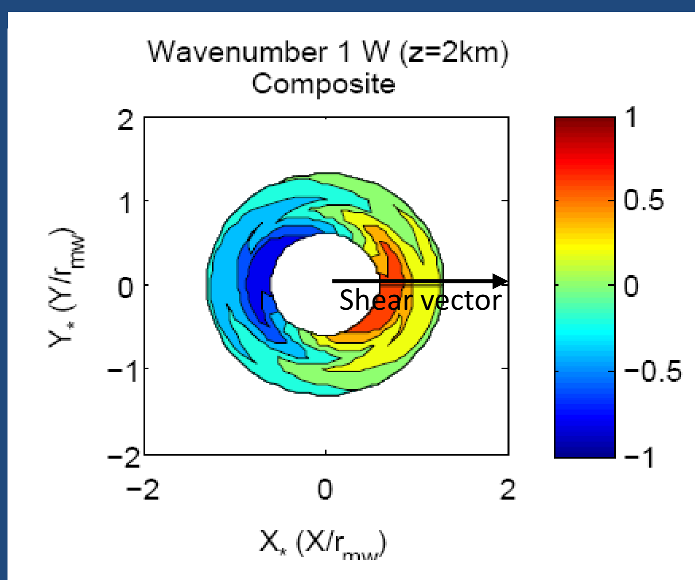
Doppler | HWRFx

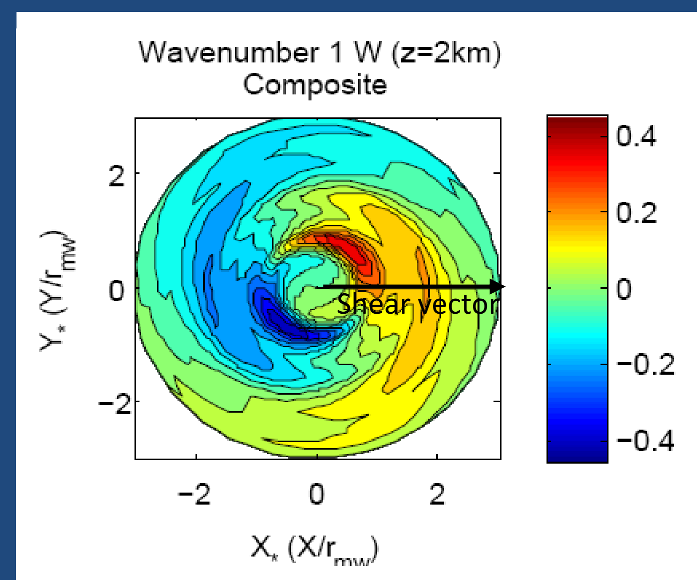
Axisymmetric





Asymmetric





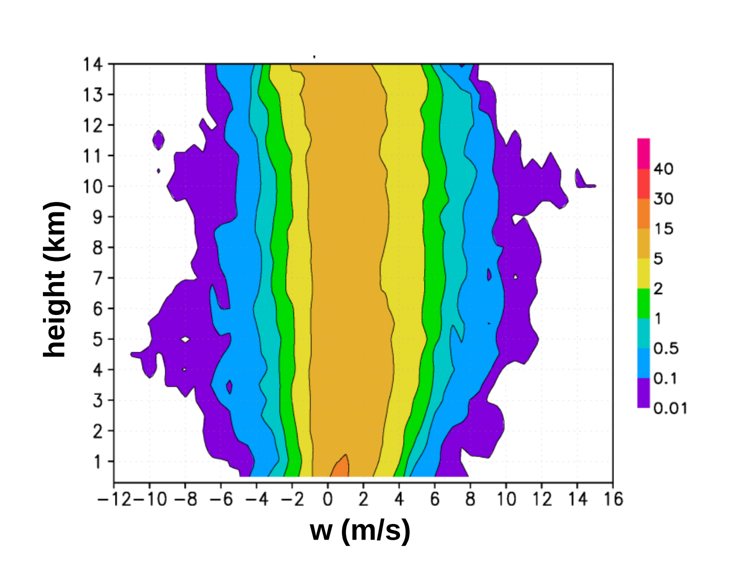
Eyewall vertical velocity

Examine multiple aspects of eyewall vertical velocity:
1) axisymmetric structure 2) asymmetric structure 3) full distribution

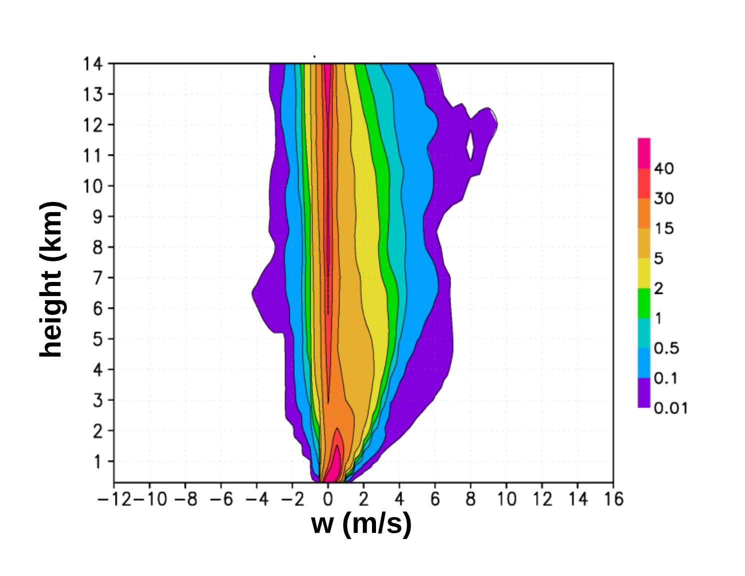
Vertical velocity CFADs (%, no precipitation masking for HWRFx)

Full distribution

Doppler



HWRFx



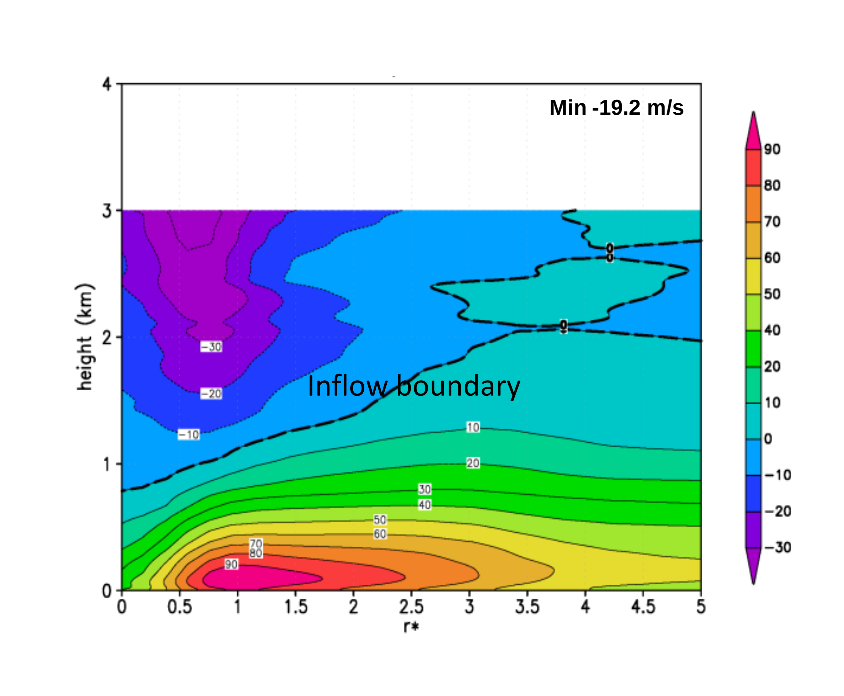
For eyewall vertical velocity, this configuration of HWRFx produces:

- weaker peak axisymmetric eyewall updraft, correct vertical variation
- less radial structure of axisymmetric vertical velocity
- updraft peak at 2-km altitude in downshear quadrant, but rotated
- narrower range of up- and downdrafts, weaker peak up- and downdrafts

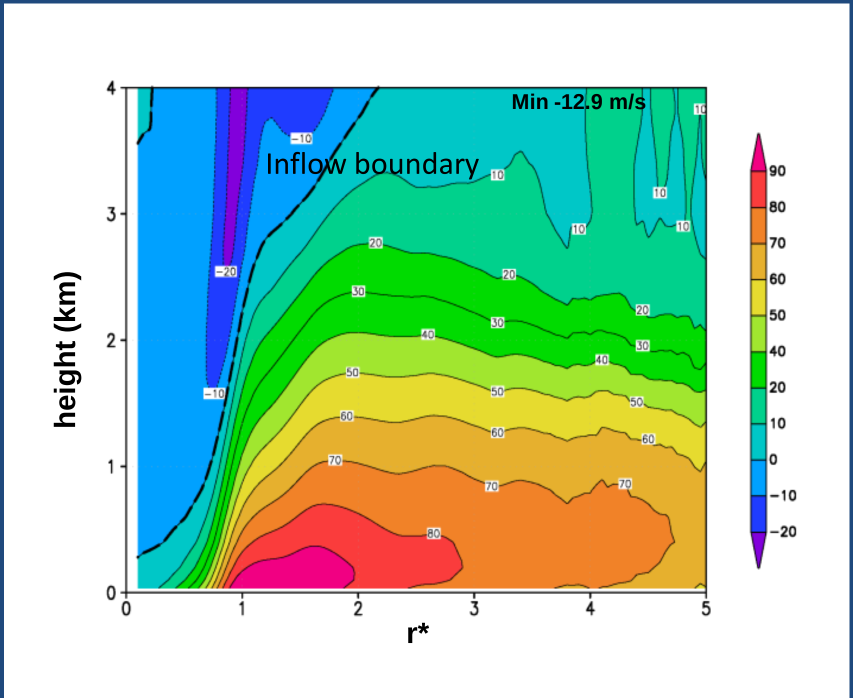
Radial flow in boundary layer

Examine axisymmetric radial flow, normalized by peak inflow value

Dropsonde



HWRFx



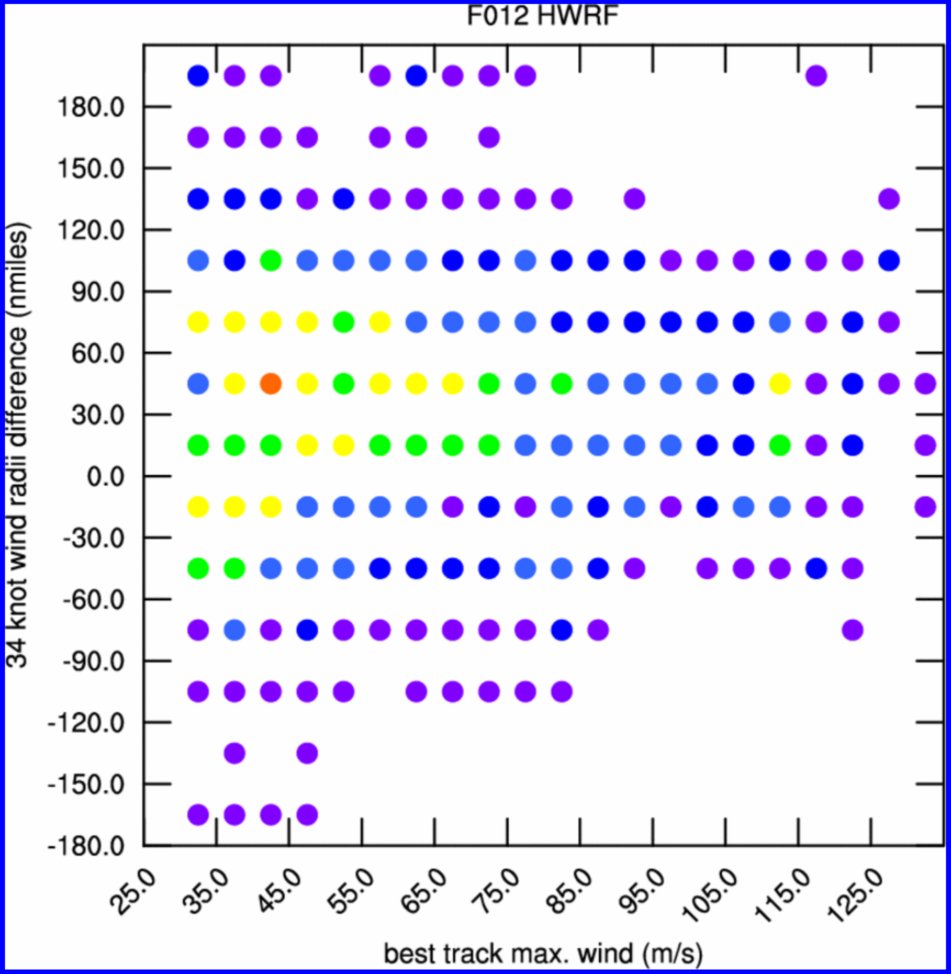
For boundary layer radial flow, this configuration of HWRFx produces:

- weaker peak inflow values
- much deeper inflow layer

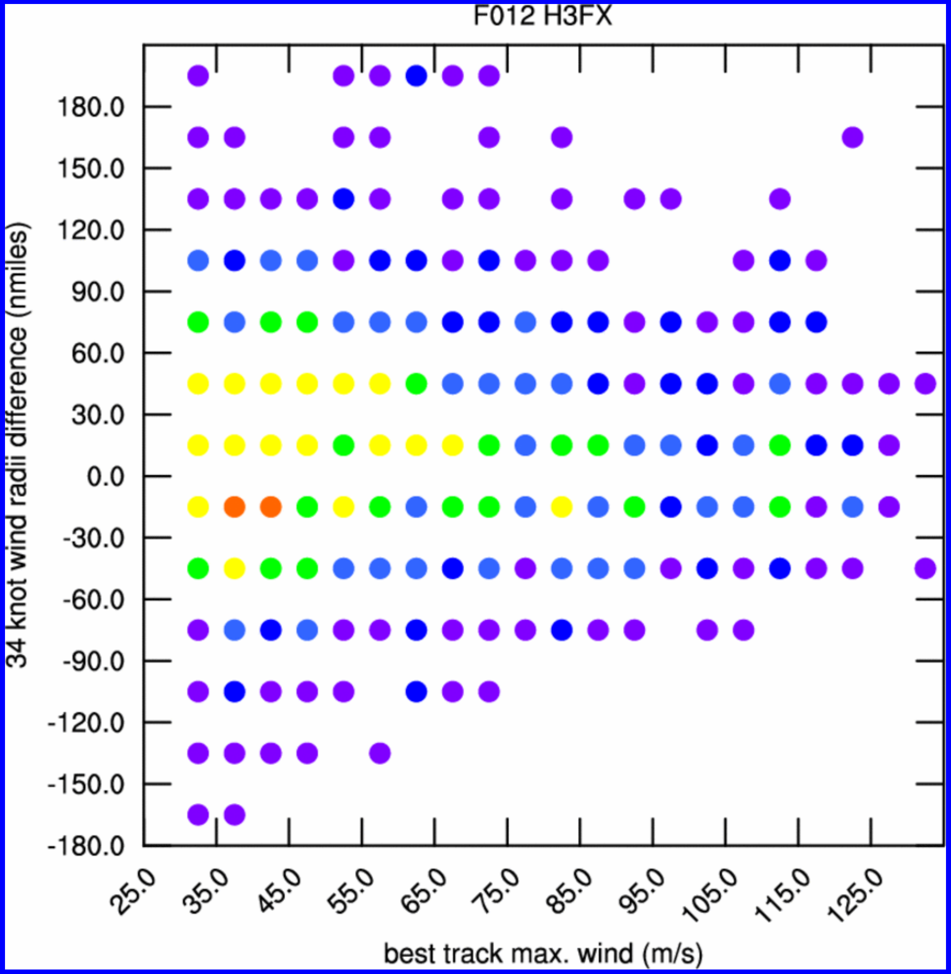
SUNYA Input

HWRF Error Histograms

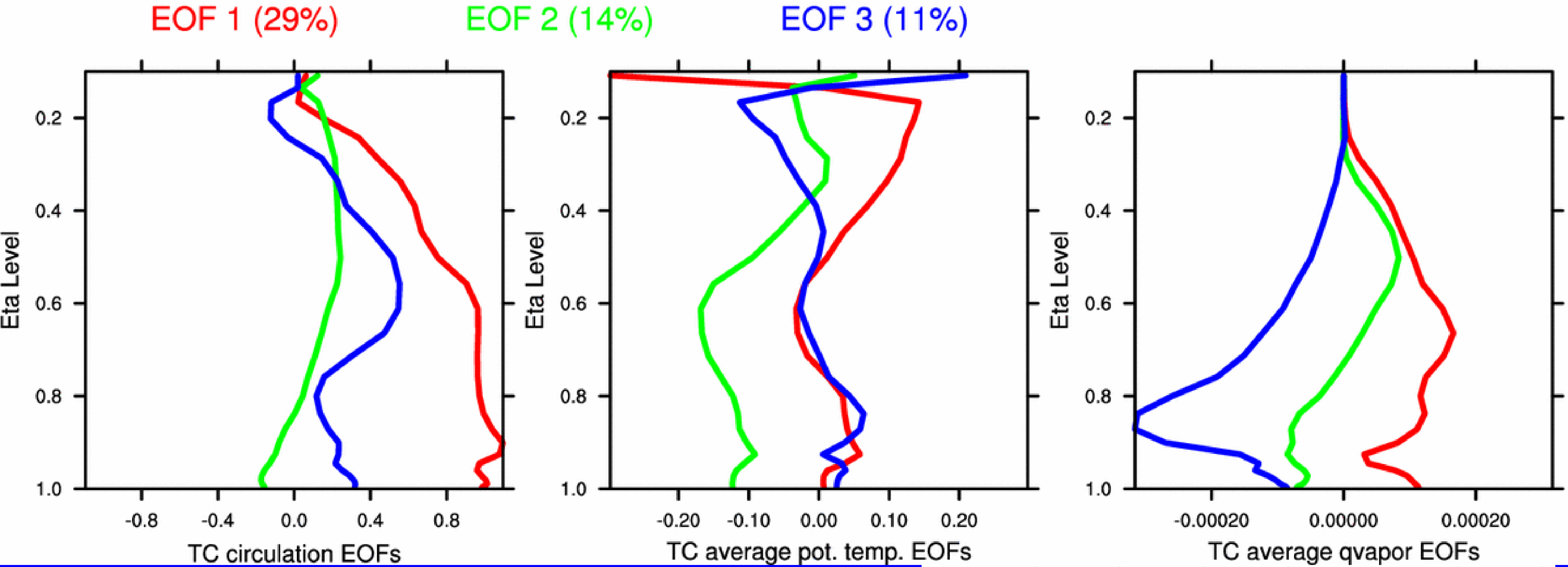
Operational HWRF



H3FX Experimental Version



Ryan Torn, U. Albany



Sensitivity of 850 hPa circulation at various lead times to First, Second, and Third EOF of initial circulation, temperature and moisture within the vortex, time-average SST, **Shear magnitude**, and upshear moisture for pre-Karl (2010). This calculation is done with a 96 member AHW ensemble.